To my wife for all her help and encouragement

Gemmological Instruments – 2nd edition

their use and principles of operation

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Preface to Second Edition

Since the first edition of *Gemmological Instruments* was published in 1978, there have been many interesting developments both in gem testing instruments and in diamond grading equipment. These developments have, in the main, consisted of improvements in the styling and versatility of existing instruments such as the refractometer, the microscope, the composite spectroscope and the reflectivity meter.

Instruments breaking new ground have been less numerous, but of major importance among these are the thermal conductivity diamond testers. These have warranted a separate chapter of their own in this second edition. The new thermal conductivity type instrument was developed as the result of the problems caused by the increasing use of that most effective of all diamond simulants, cubic zirconia. In this context, it is apt that the first commercial diamond conductivity tester was designed by one of the leading producers of cubic zirconia crystals in the USA.

Following constructive criticisms of the first edition, mention has been made, where appropriate, of the advantages and disadvantages which exist in the designs of the various items of equipment. However, as it has not been practical to examine every instrument described in the following chapters, these comments are necessarily limited to those items of equipment which have been made available for testing.

Another innovation is the inclusion of a *comparative value guide* in US dollars. Although it is appreciated that this basic price information will rapidly become out of date, the reason for its inclusion is to give a value comparison between similar types of equipment, regardless of their future cost. As before, the addresses of all organisations mentioned in the chapters are listed in Appendix A at the rear of the book.

To round off the scope of this second edition, a short section on microphotography, and an additional chapter on experimental gem test equipment have been included. The additional chapter covers those home-constructed items which although innovative have not yet been commercially exploited (in this category I have taken the liberty of including my own computer-based gem identification system). The chapter on the identification of synthetics and simulants has also been revised.

Finally, I would like to express my thanks to all my friends and colleagues who have helped to make this second edition possible, and to the various firms and organisations who supplied photographs of their equipment.

Peter G. Read

Preface to First Edition

As an engineer and gemmologist, I have found much common ground between the two seemingly diverse disciplines of electronics and gemmology. Diagnostic logic and instrumentation are perhaps the most obvious links, while an even more direct, if narrower, association is that between the ubiquitous semi-conductor devices and Type IIb diamonds.

In my work as Technical Manager with the De Beers Central Selling Organisation I have been privileged to visit some of the major diamond producing areas in Southern Africa. These have included the famous Premier mine at Cullinan near Pretoria, the Dutoitspan and Bulfontein mines at Kimberley and the Consolidated Diamond Mines coastal operation at Oranjemund in South West Africa.

Diamonds and their simulants have therefore featured prominently in both my engineering and gemmological experience. However, despite the many millions of carats of rough diamonds which I have seen passing through both the London and Kimberley sorting departments, I still find my interest caught by the infinite variety of the 'non-diamond' gem minerals. It is this interest, and my involvement with instruments, which has encouraged me to write this book to bring together in one volume descriptions of the various diagnostic instruments now available to the gemmologist. In this way it is hoped to provide a specialised extension to existing gemstone textbooks, as well as a technical review of currently available equipments. The principles of operation of each type of instrument are described, and this is followed by brief specifications of selected commercial models.

As the identification of a gemstone relies, in the main, on the measurement of its physical characteristics, the first chapter has been devoted to the definition of these constants. The second chapter deals with that essential preliminary, the cleaning and handling of gemstones, and the remaining chapters each cover specific equipments and techniques.

The sequence of chapters has been arranged to simulate, as far as possible, the order in which tests would be made in practice when identifying a gem. For example, the classification of a stone may initially be based on its colour and general appearance (Chapter 4), and this would probably be confirmed by the measurement of its refractive index (Chapter 5). If doubt still existed, the specific gravity of the stone might then be tested, where this was possible (Chapter 6). More sophisticated tests involving the stone's absorption spectrum or its luminescent properties

(Chapters 7 and 8) would be held in reserve for more difficult determinations. Chapter 12 uses the techniques described in the previous chapters in the identification of synthetics and simulants.

The instruments which are described in the chapter on Research Laboratory Equipment are perhaps outside the sphere of the majority of gemmologists, but they have been included for the sake of completeness and to give an insight into the techniques available to the research gemmologist.

The final section of the book provides a complete list of the addresses of the manufacturers and suppliers mentioned in the preceeding chapters, together with tables of gem constants listed in order of name, refractive index and specific gravity.

Peter G. Read

1

Gemstone Characteristics and Constants used for Identification

Appearance (including colour, transparency, surface and internal features, etc.). Refractive Index. Birefringence. Pleochroism. Dispersion. Specific Gravity. Absorption and Emission Spectra. Luminescence. Hardness.

This chapter, which is intended mainly for the student gemmologist, covers the basic theory necessary to understand the workings of the various gem testing instruments. The chapter is divided into two parts, the first dealing with qualitative gem characteristics (i.e. those which cannot be defined by measurement). The second part consists of definitions of those gem constants which can be measured and represented numerically.

The identification of a gemstone may be based initially on the gemmologist's knowledge and experience, but will usually be confirmed by selection of the appropriate scientific tests. As with any diagnostic work, whether it is the tracing of a faulty component in a computer, or the analysis of the constituents of a moon rock, full use is made of the human senses of sight, touch and, sometimes, smell and taste. The instruments used to test the more specific properties of a gemstone can, in fact, be regarded as extensions to these senses, and with growing experience, these tests often do no more than confirm first impressions.

THE APPEARANCE OF THE GEMSTONE

When attempting to identify a gemstone, we would normally hope to assemble a variety of clues to confirm our initial hunch or intuition. Some of these clues may be as basic as the general appearance of a stone, its colour, lustre and sheen, and its internal features. Of these, colour is perhaps the first quality that is taken into account, and, although seldom conclusive, its main help is to narrow down the number of possibilities.

There are, unfortunately, few gemstones whose colour alone is distinctive enough to allow a confident identification (e.g. the fresh grass green of peridot, or the more sultry shade of green tourmaline). Furthermore, some gems, such as sapphire, can occur in a variety of colours. The mineral beryl, for example, may appear as the yellow heliodor, the pink morganite, or the colourless goshenite, as well as the more familar emerald and aquamarine.

An initial impression of a gem's identity, based on qualitative evidence, will of course rely heavily on past experience, and where this fails, reference books can often help. However, before a reference book can be used effectively, the student gemmologist must know the meaning of the terms used to describe the characteristics which contribute to appearance. The following definitions will serve as a reminder.

Transparency

This is the degree to which a stone transmits light. Transparency, or its converse, opacity, can be described for identification purposes as follows:

Transparent. An object viewed through the stone or mineral can be seen clearly, with its outlines easily visible. (Examples: rock crystal and diamond).

Semi-transparent. The image of an object viewed through the stone will be blurred but still recognisable. (Example: fire opal and moonstone).

Translucent. The stone will transmit some light, but objects cannot be seen through it. (Examples: chalcedony, and jadeite).

Semi-translucent. Some light can still penetrate the stone, but only through the edges. (Examples: turquoise and nephrite).

Opaque. The stone is sufficiently dense optically to prevent the passage of any light. (Examples: malachite and lapis lazuli).

It should be remembered that transparency is also partly affected by colour, i.e. dark coloured stones are less transparent than light coloured ones. Another factor which will affect transparency is the presence of internal flaws and inclusions. In addition, the thicker the stone, the greater will be the attenuation of light passing through it. Conversely, even opaque minerals will become translucent if they are ground thinly enough.

Lustre

Lustre is the optical effect created by light reflecting from the surface of the stone, and is directly related to the quality of the surface polish which can be produced on a stone. In general, the harder the stone and the higher its refractive index, the more perfect will be the degree of polish attainable on its facets. The adjectives which are used to describe a stone's lustre are as follows:

Metallic. The highly reflective surface lustre as seen in pyrite and galena crystals.

Adamantine. The high surface lustre associated with diamond, high zircons and demantoid garnet.

Vitreous. The lustre attained with most gemstones (a glass-like finish).

Resinous. As in amber.

Waxy. As in turquoise, opal and jadeite.

Greasy. As in nephrite and grossular garnet.

Pearly. As in pearl and moonstone.

Silky. As in satin spar.

The relative lustre of gemstones can be measured by means of a reflectivity meter, and as lustre has a direct relationship to the refractive index of a gem, this provides a method of identification (see Chapter 6).

Sheen

Sheen is the optical effect created by the reflection of light from beneath the surface of the stone. The effect is caused by various structural arrangements within the stone, of which the following are examples:

Chatoyancy. This is the 'cat's eye' effect caused by the reflection of light from parallel groups of fibres, crystals or channels within the stone. In the case of pseudocrocidolite (tiger's eye), these channels are the fossilised remains of asbestos fibres which have been replaced by quartz. The finer and more highly reflective the fibres or channels, the brighter is the chatoyant 'line' which is produced. While many stones can be polished into the rounded cabochon shape to reveal chatoyancy, the finest quality cat's eye stones are found in a variety of chrysoberyl known as cymophane.

Asterism. This is a star effect present in some rubies and sapphires (which are usually cut in cabochon form to show the effect to best advantage). Like chatoyancy, the effect is also due to parallel fibres or channels, but in this case there are three sets of parallel fibres intersecting each other at 60 degrees. Although the best asterism occurs in corundum with a six-pointed star, it can also be seen sometimes in rose quartz, and as a four-pointed star in some garnets, where the fibres are at 90 degrees to each other, and in diopside, where the fibres are at 73 degrees to each other.

Opalescence. This is the silvery or pearly reflection shown by common opal, and is caused by the effect of light reflecting from thin layers in the internal structure of the stone.

Adularescence. Also known as 'Schiller', this is the bluish sheen seen in moonstone, and is caused by thin plates (formed by laminar twinning) within the stone which 'interfere' with the reflected light (i.e. some of the colour components in the white light are cancelled and some are reinforced).

Iridescence. This is the 'play' of rainbow coloured light from the surface layer of a stone, and, in the case of precious opal, is the result of the 'interference' of light by a thin surface layer composed of a regular pattern of microscopic spheres.

Fire. The flashes of coloured light seen emerging from a stone as it is rotated in a beam of light. This effect is seen in a transparent stone having high 'dispersion' (defined in second half of chapter). Stones exhibiting fire to a marked degree are diamond, demantoid garnet, sphene (titanite) and zircon.

Brilliance. This is an effect which depends on both the surface and internal reflections of light, the latter quality being the ability of a stone to reflect back through its crown facets the majority of the light entering it through these facets. The angles of the crown and pavilion facets must be chosen carefully with regard to the stone's refractive index, so that total internal reflection is achieved for the majority of light rays entering the stone. The white and sparkling appearance of a faceted diamond is known as its 'life'.

Fracture

The way in which a stone breaks (other than by cleavage or parting) is known as *fracture*. The type of fracture can be a useful identifying feature, and it is sometimes rewarding to examine the edges of faceted stones or crystals for signs of fracture damage. Typical types of fracture are:

Conchoidal, or shell-like, as in quartz, glass and garnet.

Splintery, where the fracture is in the form of long splinters, as in jade and ivory.

Smooth, or even, as in diamond.

Hackly, or uneven, as with amber.

Cleavage

Cleavage is the property of a stone to divide along a plane of weak molecular bonding. A cleavage plane will always occur parallel to a natural crystal face. Some minerals, such as topaz and fluorite, cleave very readily, and nascent cleavage planes can often be seen within the stone.

Pseudo-cleavage or *parting* occurs in some crystals which are not subject to cleavage, but even so have a direction of weakness known as 'parting'. It occurs occasionally in minerals such as ruby and labradorite, which show laminar twinning.

Inclusions

These are foreign materials (solid, liquid or gaseous) inside a gemstone. They can often be of great help in identifying a stone, and particularly in deciding whether a stone is a natural, a synthetic or a simulant.

The country of origin of the stone may sometimes be determined by a study of its inclusions. Gemstone inclusions are divided into three classifications:

1. *Pre-existing.* These inclusions were present before the formation of the host crystal, and often take the form of crystals of other minerals, or of the host mineral.

2. *Contemporary.* Inclusions of this type were formed at the same time as the host crystal, and often consist of voids containing the liquor from which the stone crystallised.

3. *Post contemporary.* These may take the form of networks of very fine cracks called 'feathers' which are caused by some of the host mineral liquid (trapped in cracks in the crystal as it solidified) finally crystallising out.

The descriptive names given to some of the more common inclusions are as follows:

Feather. A fine network of cracks or bubbles resembling a feather, a piece of lace, or a fingerprint.

Horse tail. Groups of asbestos fibres forming a 'curl' (often found in demantoid garnet).

Silk. A group of fine parallel needle-like inclusions, usually intersected at an angle by a second similar group (found in ruby and sapphire).

Two-phase inclusion. This can take the form of a void containing either a liquid and a gas bubble (found in quartz, topaz, tourmaline and beryl) or a liquid and a crystal.

Three-phase inclusion. This is a void containing a liquid, a bubble of gas and a crystal (in an emerald this indicates that it came from the Colombian mines).

Rain. A series of short parallel needle-like inclusions.

Negative crystal. A void having the shape of a crystal.

Zircon 'Halo'. Stress cracks surrounding a zircon crystal inclusion (found in some rubies, sapphires and pyrope garnets).

The use of inclusions to identify stones, and to distinguish between natural and synthetic gems, is covered in detail in several gemmological books[1]. A brief summary of typical inclusions in natural and synthetic gemstones is included at the end of Appendix B.

Shape

So far we have discussed the classification of polished or faceted gemstones, but there are occasions when it is necessary to be able to identify a gem mineral specimen in its rough or crystal form. Many of the foregoing comments about colour, inclusions, cleavage, etc, will of course still apply to the unpolished gem mineral. However, the 'habit', or natural crystal shape, which many gem minerals adopt, can also be of value when identifying an unknown crystal.

A gem mineral may belong to any one of seven crystal systems, and these systems can be defined in terms of the relative lengths and angular relationships between imaginary lines of reference. These lines, which are called axes of reference, represent the length, breadth and height of the crystal, and pass through its centre to meet at a point called the 'origin'. In the illustrations which accompany the descriptions of the seven crystal systems, an attempt is made to show some of the crystal habits associated with each system.

Cubic

This has the highest symmetry of all the systems. It has three axes, all of equal length and all at right-angles to each other. Common forms are:

Cube (*Figure 1.1a*). Examples: diamond (rarely), fluorite, pyrite.
Octahedron (8-sided, *Figure 1.1b*). Examples: diamond, spinel.
Dodecahedron (12-sided, *Figure 1.1c*). Examples: diamond, garnet, pyrite.
Icositetrahedron (24-sided, *Figure 1.1d*). Examples: diamond, garnet.

Tetragonal

(*Figure 1.2*). This has two equal axes at right-angles to each other, and a third or principal axis of different length to the first two, and at right angles to them. The commonest forms in this system are four-sided prisms. Example: zircon.

Hexagonal

(*Figure 1.3*). There are four axes in this system, the first three being of equal length and lying in the same plane, but inclined at 60° to each other, and the fourth, the principal axis, being perpendicular to them, and of a different length. The commonest form is the six-sided prism. Example: beryl.

Trigonal

(*Figure 1.4*). This system has four axes which are disposed in the same way as those in the hexagonal system. Trigonal crystals often appear as six-sided prisms. A common form is also the three-sided prism. A large number of gem minerals crystallise in the trigonal system. Examples: corundum, quartz, tourmaline.

Orthorhombic

(*Figure 1.5*). This system has three axes, all at right-angles to each other, and all of different lengths. Examples: chrysoberyl, peridot, topaz.

Figure 1.1
Common forms in the Cubic system

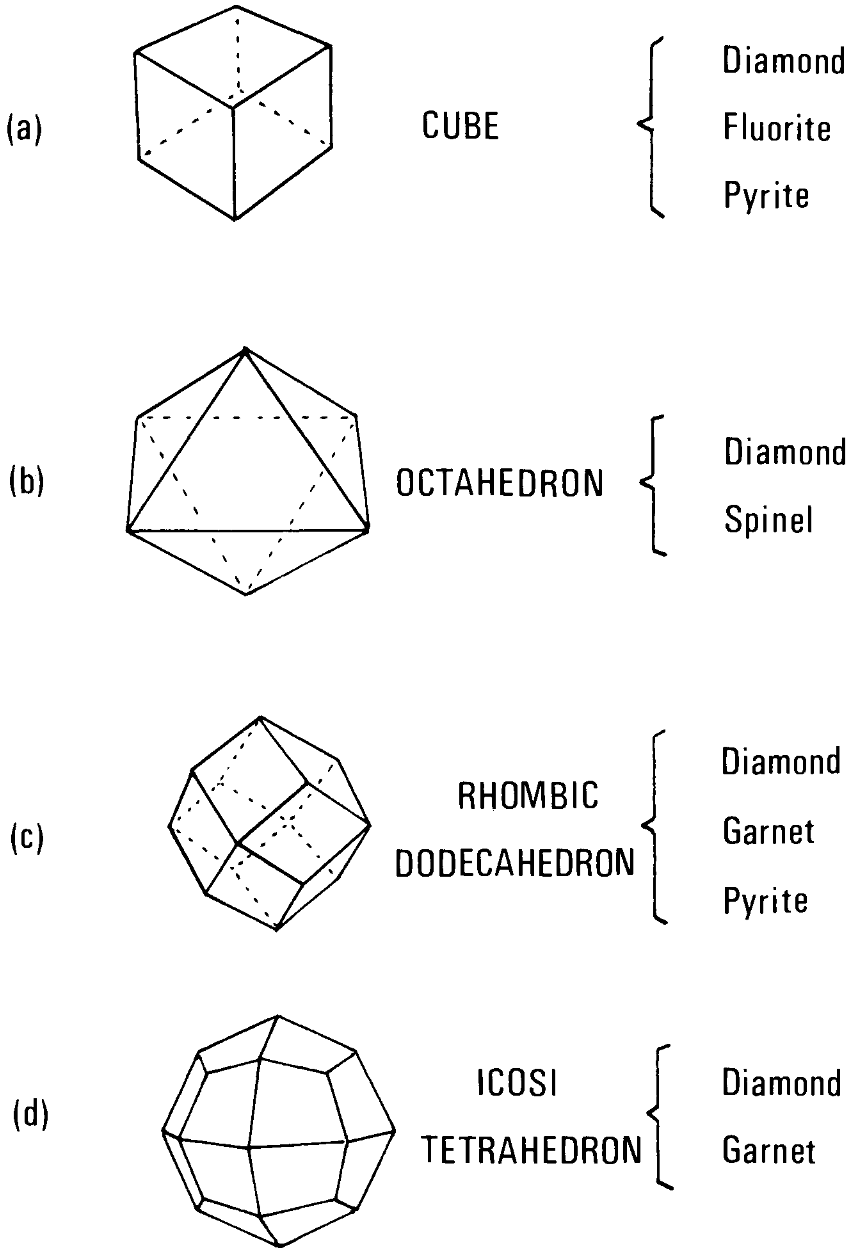


Figure 1.2
Crystals in the Tetragonal system

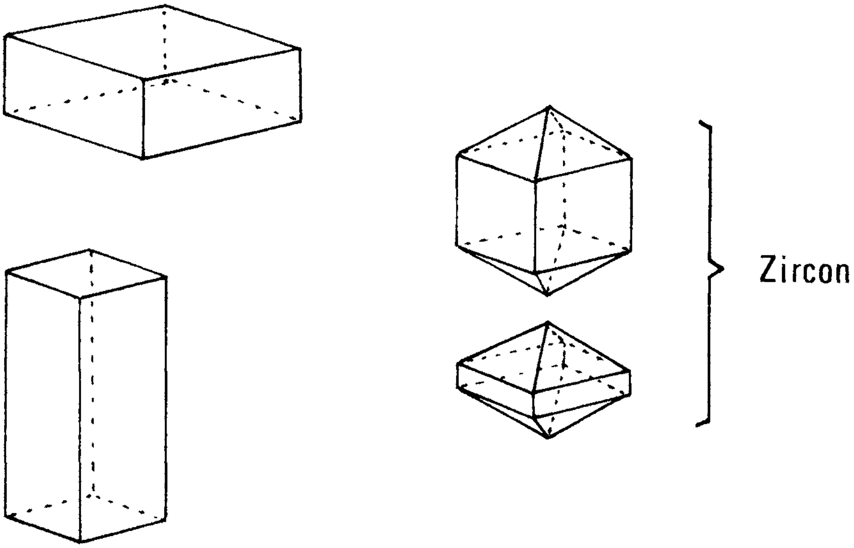


Figure 1.3
Crystals in the Hexagonal system

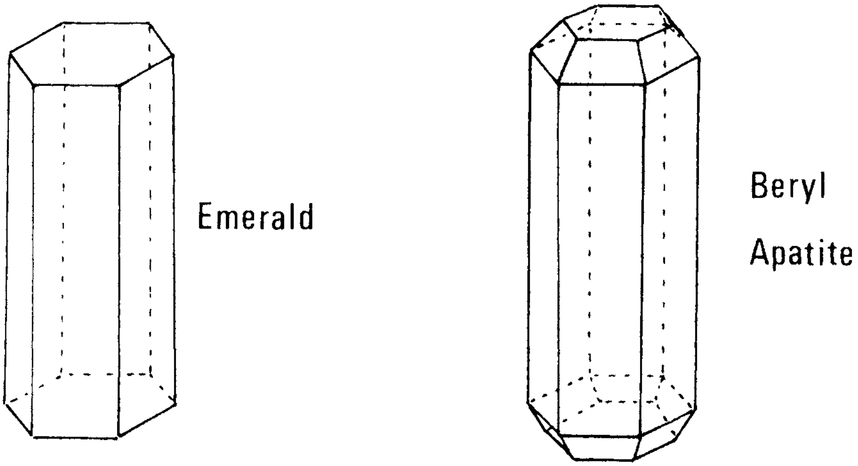


Figure 1.4
Crystals in the Trigonal system

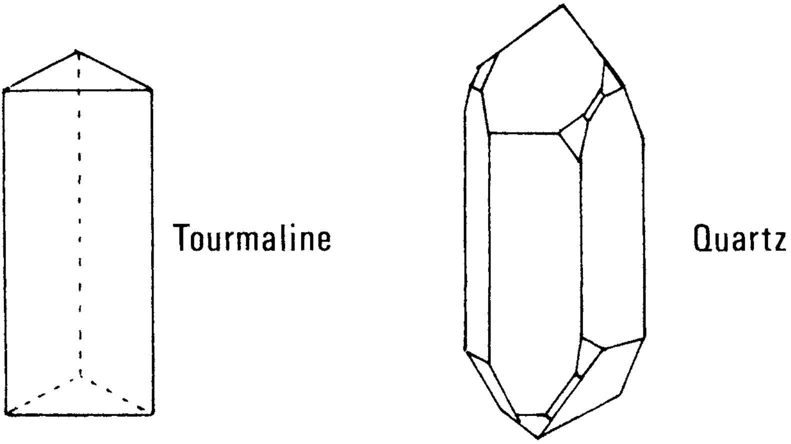
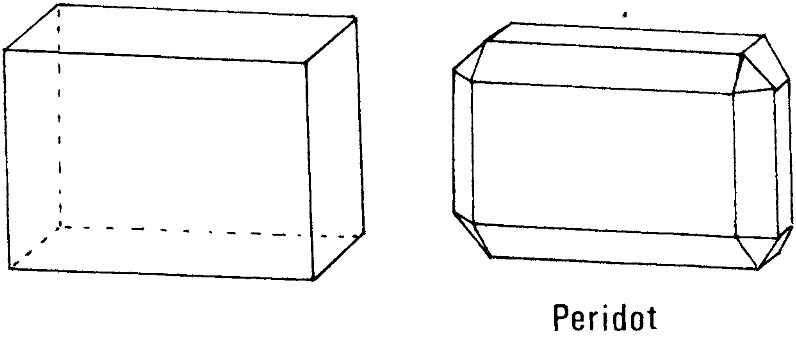


Figure 1.5
Crystals in the Orthorhombic system



Monoclinic
(*Figure 1.6*). There are three axes in this system, all of different lengths. Two axes are inclined at an angle to each other in the same plane, and the third axis is perpendicular to the other two. Examples: sphene, spodumene.

Triclinic
(*Figure 1.7*). This is the least symmetrical of the seven systems. It has three axes, all of different lengths, and all inclined to each other. Examples: amazonite feldspar, moonstone, kyanite.

Figure 1.6
Crystals in the Monoclinic system

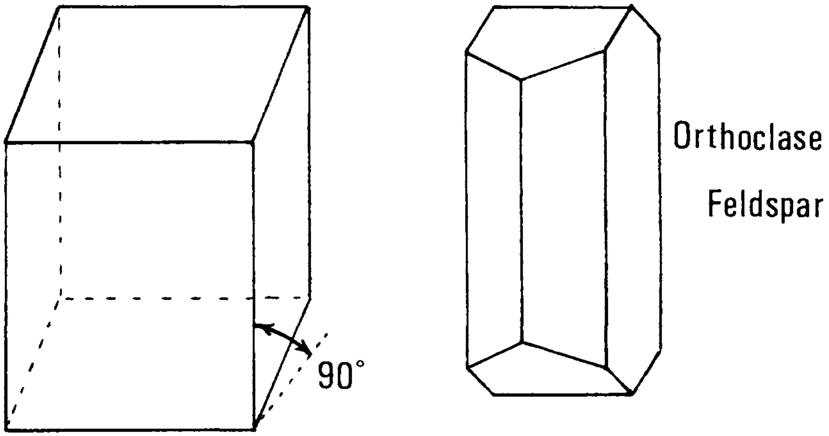
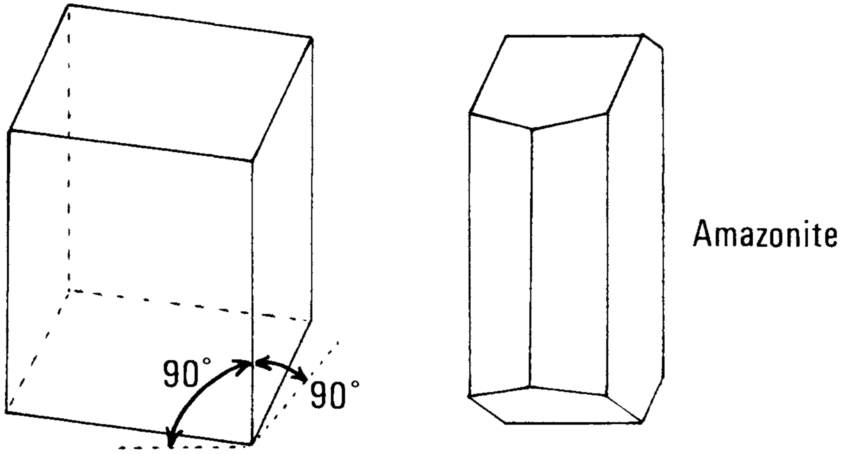


Figure 1.7
Crystals in the Triclinic system



Terms which describe crystal shapes

The following are a few of the terms which are used to describe crystal shapes and features:

Acicular
Slender needle-like crystals (e.g. rutile needles in quartz).

Botryoidal
Resembling a bunch of grapes (e.g. haematite).

Contact twins
This is where the twin-halves of a crystal have grown with one half rotated through 180 degrees to the other half. In diamond, a contact twin is called a 'macle'.

Dendritic
When applied to an inclusion, describes a 'branching' feature (e.g. as in moss agate and green tree agate).

Interpenetrant twins
Here, two (or more) crystals have grown in proximity and have penetrated each other.

Mammillary
Large spheroids intersecting each other (e.g. malachite).

Massive
Without crystal form (e.g. rose quartz, jasper).

Parallel growth
Unlike other twinned crystals, the faces of parallel growth ones have the same orientation.

Pinacoid
A pair of crystal faces which are parallel to two crystal axes and cut by a third. In a basal pinachoid, the faces often form the terminating ends of a prism.

Prism
A crystal form whose faces are parallel to the principal axis and are cut by the lateral axes (see *Figures 1.2, 1.3* and *1.4*).

Striations
Growth lines on the surface of a crystal (e.g. the faint horizontal lines on a quartz prism; the deep vertical lines on a tourmaline prism).

Tabular
A crystal having a flattened tablet-like habit (e.g. peridot).

For a more detailed description of gem crystal systems, reference should be made to the various gemmological books[2] which cover this subject in greater depth.

GEM TESTING

Now that we have covered the terms which are used to describe some of the qualitative features which contribute to a stone's appearance, we can turn to the stone's quantitative characteristics or constants. This is the point in the process of identification where we move from inspecting to testing.

There are many tests which can, in principle, be applied to a gemstone, although in practice it may not always be possible, or wise, to use all of them. For example, it would not be practical to measure the specific gravity of a stone mounted in a ring, without first removing it from its setting, and this, except in extreme circumstances, would not be necessary as other confirmatory tests could be applied.

Methods of testing

This is perhaps a good place to discuss the two broad categories into which tests can be divided. The first contains those tests which simply narrow down the number of possible minerals under which the stone could be classified, and the other comprises tests which are confirmatory, that is where there can be no doubt of the stone's identity.

As an example of the first category, we could test a colourless transparent stone for its optical character. If the test revealed that the stone was isotropic (i.e. singly refractive), then it could be one of several isotropic stones, and further tests would have to be applied to identify it as a diamond, synthetic spinel, blende, strontium titanate, cubic zirconium oxide, YAG or paste.

As an example of a confirmatory test, we could take the same colourless stone and check its luminescent properties under a long wave ultra violet lamp. If the stone fluoresced blue, and, when the lamp was switched off, exhibited a yellow afterglow, this would be a confirmatory test for diamond, as no other blue fluorescing gem mineral shows this characteristic yellow afterglow.

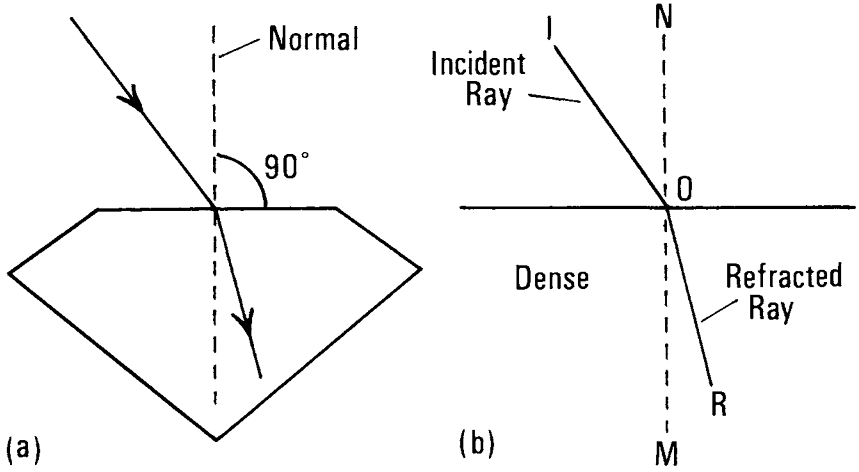
The remainder of this chapter defines the quantitative characteristics by which a gemstone can be identified. From this starting point we can then begin to look in detail at the instruments which have been designed to measure these constants.

Refractive index

When a ray of light passes from one medium (such as air) into another medium of greater optical density (such as a gemstone), the ray is refracted or bent towards the normal (see *Figure 1.8*(a)). Conversely, when the ray leaves the gemstone and passes into the air, it is refracted away from the normal.

The greater the difference between the optical densities of the two mediums (or, in the case of air and a gemstone, the greater the optical density of the gem), the greater will be the amount of refraction.

Figure 1.8
The incident light entering a gemstone from air is refracted towards the normal (a). A light ray leaving the gemstone and passing into air will be refracted away from the normal. The refractive index for the denser gemstone medium is the ratio of the sines of the angles ION and MOR (b) and is derived from Snell's law of refraction



As the optical density of each gemstone is specific to that gemstone, it is a very useful means of identification. The ratio between the optical density of the gemstone and that of air (the latter being taken as a constant) is known as the Refractive Index of the gem.

The refractive index can, in fact, be defined in three different ways:

1. The ratio of the sine of the angle of incidence in air (ION) to the sine of the angle of refraction in the gem (MOR), see *Figure 1.8(b)*.
2. The ratio of the optical density of the gem to that of air.
3. The ratio of the velocity of light in air to the velocity of light in the gem.

Because refractive index varies with the wavelength (or colour) of the light, it is common practice to state the Refractive Index of a stone in terms of yellow sodium light (which has a wavelength of 589.3 nm, 5893 Å). Sodium light is chosen as it is bright and easy to produce. If a red light were used, this would produce a lower Refractive Index value. Blue light would produce a higher Refractive Index value. The range of gem refractive indices extends from 1.43 for fluorite to 2.75 for rutile.

Birefringence (double refraction)

Light passing through an amorphous (non-crystalline) substance, such as amber or glass, or through a gemstone belonging to the cubic crystal system, will obey the optical laws of refraction as described under

'Refractive Index'. The incident ray results in a single refractive ray regardless of the direction in which the ray enters the gem. Such gems and substances are called Isotropic, and are singly refractive.

However, when a ray enters a gem mineral belonging to one of the other six crystal systems, it is split into two rays which are plane polarised at right-angles to each other. These two rays travel through the gem at different speeds, and as with light of different wavelengths, they are refracted by different amounts. Gems which cause light to split into two polarised rays are called doubly refractive, birefringent or anisotropic.

The amount and kind of double refraction is an important factor when identifying a gemstone. The amount of double refraction is obtained simply by subtracting the Refractive Index of the lowest ray from the Refractive Index of the highest ray. Stones having a high double refraction, such as zircon (0.058) can usually be identified by the obvious double image of the back facets when viewed through the table facet with a 6X or 10X hand lens.

Anisotropic (birefringent) stones possess either one (uniaxial) or two (biaxial) directions along which light is not doubly refracted. These directions of single refraction in an otherwise doubly refractive stone are called optical axes, and can be identified with an instrument known as a konoscope (see Chapter 5).

The six anisotropic crystal systems can be sub-divided into two groups as follows:

Tetragonal Hexagonal Trigonal	Uniaxial	Orthorhombic Monoclinic Triclinic	Biaxial

This gives us a further method of identifying a gemstone. Those gems belonging to the uniaxial group will show one constant Refractive Index for any direction of ray, while the Refractive Index of the second ray will vary as the angle of entry of the ray is varied relative to the optical axis. In those gems belonging to the biaxial group, the Refractive Index of both rays will vary as their angle of entry is varied. These facts will become relevant when dealing with the principles and use of the refractometer in Chapter 5.

Pleochroism

This is the generic name given to the optical quality, which some stones possess, of splitting the light passing through them into two or three different shades or colours (called dichroism and trichroism respectively). We have already discussed (under 'Birefringence') how light which passes into a anisotropic gem is split into two rays which are plane polarised at right-angles to each other, and how these two rays are refracted by different amounts. In a coloured anisotropic gem, these two rays, which are travelling at different speeds, may emerge differing in colour or shade (i.e. a different portion of the visible spectrum has been absorbed from each ray).

When such emerging rays are seen to differ in shade or colour, this not only proves that the gem is anisotropic, but the colours or shades of colour in themselves constitute an important means of identifying the stone. Instruments for optically separating these colours (called dichroscopes) are described in Chapter 4.

The following stones all exhibit varying degrees of pleochroism:

Ruby – two shades of red
Sapphire – two shades of body colour
Tourmaline – two shades of body colour
Andalusite – green, yellow, red
Iolite – pale blue, dark blue, pale yellow
Zoisite – blue, purple brown
Alexandrite – green, yellowish, pink (daylight); red, yellowish-red, green (filament light)

Dispersion

Dispersion of white light occurs immediately it enters an optically dense medium (such as a gemstone) from air. The white light is split into its component colours, each of which is refracted by a different amount in the gem (red light is refracted least, and violet light the most). On emerging from the gem, the individual colour components of the white light are responsible for the 'fire' which is exhibited by diamond, zircon, rutile, strontium titanate and sphene (*Figure 1.9*).

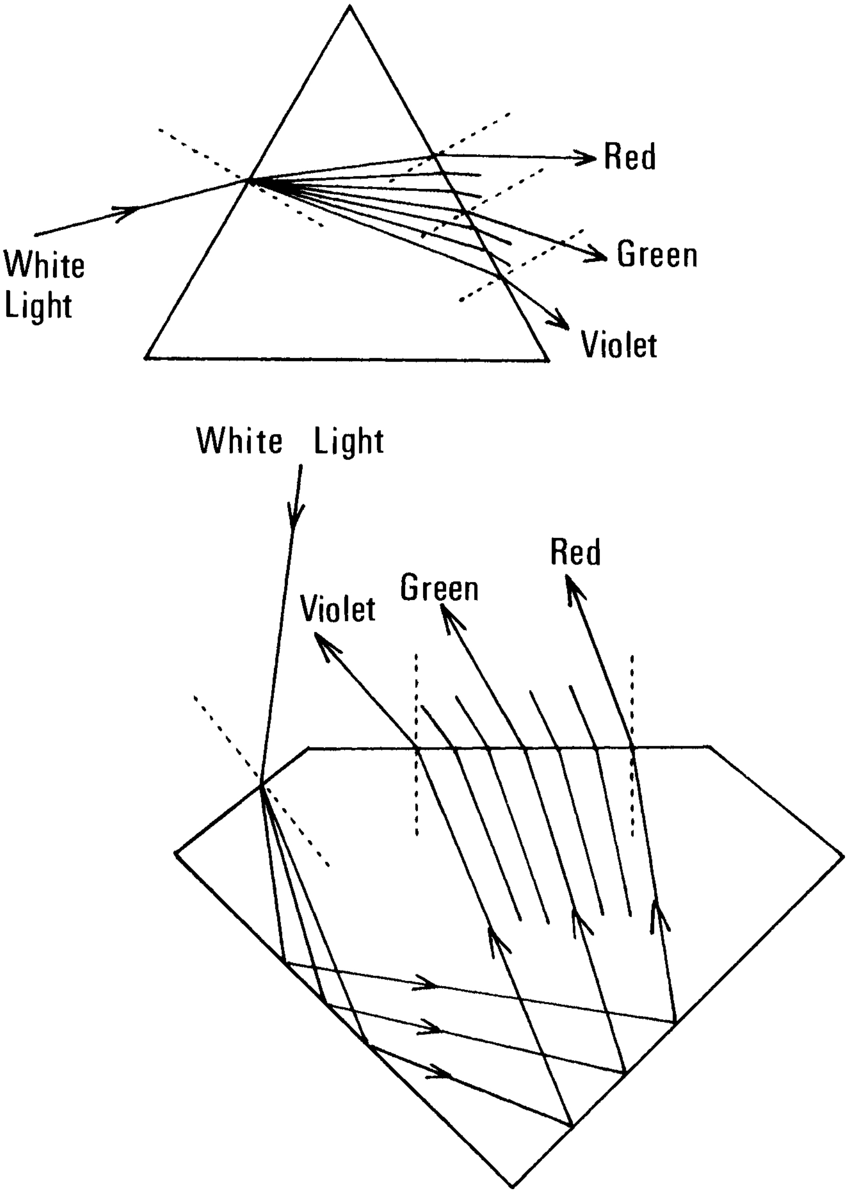
Dispersion is in fact a measurable optical property of a gemstone, the higher the value of dispersion (0.044 in diamond, 0.051 in sphene) the more fire the gem shows. It is measured as the difference in the refractive index of a gem at two selected wavelengths, one in the red and one in the violet. These two wavelengths are chosen as the B and G Fraunhofer lines, and are standards which can be observed as sharp absorption lines in the sun's visible spectrum. The B line is in the red at 687 nm (6870 Å) and the G line is in the violet at 430.8 nm (4308 Å).

Specific gravity

This is the ratio of the weight of a body to the weight of an equal volume of pure water at 4°C. It is an important diagnostic constant of a gemstone, and can be expressed as $A/(A-B)$, where A is the weight of the gemstone in air, and B is the weight of the gemstone when totally immersed in water.

In practice it is desirable to use distilled water, but for the purpose of gem testing, it is not necessary to keep it at 4°C. If a liquid other than water is used, the simple formula given above must be multiplied by the specific gravity of the liquid, and a correction made for temperature. By definition, the specific gravity of water is 1.0, and that of gemstones varies from 2.0 for fire opal to 4.68 for zircon. Methods for measuring specific gravity are described in Chapter 7.

Figure 1.9
White light entering a prism (top) is dispersed into its component colours, the individual rays being refracted in varying degrees towards the normal as they enter the prism, and away from the normal as they leave it. White light is similarly dispersed when it enters a gemstone (bottom), and after being internally reflected by the gem's pavilion facets the component colours emerge from the crown facets to give the gem its characteristic 'fire'



Absorption and emission spectra

Absorption and emission spectra of a gemstone are produced by passing a white light through the stone (or reflecting the light off the surface of the stone) and then inspecting this light by means of an instrument called a spectroscope. The spectroscope spreads the transmitted or reflected light out into its component colours, and it is then possible to see how the gemstone has modified the original white light.

One way in which it may have modified the light is by selective absorption of certain wavelengths. This is often caused by what are called transition elements, which are present in some stones and which cause dark absorption lines or bands to appear in the spectrum displayed by the spectroscope.

The transition elements, with examples of gems which contain them, are as follows:

Chromium. Ruby, emerald, alexandrite, red spinel, pyrope garnet, chrome grossular garnet.

Cobalt. Blue synthetic spinel, smithsonite.

Copper. Malachite, turquoise.

Iron. Green sapphire, zircon, aquamarine, almandine garnet, blue spinel.

Manganese. Rhodochrosite, rhodonite, spessartite.

Nickel. Chrysoprase.

Titanium. Blue sapphire.

Vanadium. Blue zoisite, green vanadium beryl, synthetic corundum (doped with vanadium to produce an alexandrite simulant).

There are, in addition, a group of so called 'rare earth' elements (sometimes present in gemstones and also used as dopants in the preparation of synthetic crystals) which do not necessarily alter the colour of the gemstone, but which give very distinctive and recognisable absorption spectra. These are called fine line spectra, and may be present as groups of fine lines as in apatite, or may appear as a continuous series of fine lines across the spectrum as with some YAGs.

The absorption spectrum produced by a gemstone containing one or more transition elements (or a rare earth) is often sufficiently recognisable and repeatable to be used as a confirmatory test. In addition, the absorption spectrum produced by some of the elements such as chromium and iron can be recognisable enough to be identified clearly in a gemstone's spectrum.

Occasionally, as well as dark absorption lines in a spectrum, bright fluorescent lines, known as emission lines, may also be present. These are caused by the light energy being absorbed by the transition elements in the stone, which then re-radiate it at their own characteristic wavelengths. Red spinel often displays emission lines in the red, which are strong enough to be called 'organ pipes'.

Until the student gemmologist becomes sufficiently conversant with the characteristic spectra of the various gem minerals, it is recommended that the advice on the application of the spectroscope, together with the reproductions of spectra, which are contained in various gemmological books[3], are studied and used as a source of reference.

Luminescence

The property of a substance to absorb energy (which may be in the form of light, heat, electricity, friction etc.) and to convert it to light of a particular wavelength is known as *luminescence*. If the source of the energy is in the form of electro-magnetic radiation (i.e. radio waves, infra-red, visible light and ultra-violet light) then the emitted radiation will be longer in wavelength than the applied radiation.

There are two particular forms of luminescence which are of interest in gemmology and are used in identifying gemstones. These are:

1. *Fluorescence*. This occurs as soon as the source of energy (visible light, ultra-violet light or X-rays) is applied to the gemstone, and stops immediately the energy is removed.
2. *Phosphorescence*. This is an 'afterglow' which occurs in some gemstones when the source of energy is removed. This afterglow decays and the decay time may vary from less than a second in some minerals, to several seconds in others.

Some gem minerals both fluoresce and phosphoresce, and the resulting effect is then for the colour and intensity of the luminescence to change when the energy source is turned off. The usual sources of energy available to the gemmologist are visible light, and long wave and short wave ultra-violet light (X-rays, because of the bulkier equipment and the associated precautions, are perhaps more in the province of the larger laboratory). When using visible light to excite fluorescence in a gemstone, the light is usually filtered to remove the longer wavelengths, as these would otherwise mask the fluorescence produced by the stone.

Many gem minerals produce characteristic luminescent colours when subjected to the various wavelengths of energy, and this can be a useful additional aid to identification.

Hardness

Hardness is defined (for gemmological purposes) as the ability of a substance to resist abrasion when a pointed fragment of another substance is drawn across it without using sufficient pressure to cause cleavage.

The scale of relative hardness used by gemmologists and mineralogists was devised by the German mineralogist Friedrich Mohs. This scale is based on the premise that any mineral with a given hardness number will scratch a mineral having a lower number, and will itself be scratched by a mineral of a higher number.

Friedrich Mohs selected ten relatively common minerals as standards, and numbered them one to ten in increasing order of hardness. The standard minerals used in the Mohs scale reads as follows:

1. Talc
2. Gypsum
3. Calcite
4. Fluorspar
5. Apatite
6 Orthoclase feldspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

It must be remembered that the Mohs hardness scale is not a linear one (i.e. the difference in hardness between corundum at 9 and diamond at 10 is much greater than the difference between talc at 1 and corundum at 9).

Although a hardness test may occasionally be resorted to when other tests have failed, it is generally best avoided for the following reasons:

1. It damages the stone under test.
2. Many stones have a similar hardness, and the test is therefore not confirmatory.
3. In many cases it is not easy to apply.
4. Generally, there are more reliable tests available.

There are, however, some limited occasions when a hardness test is permissible. One of these is where a large gem mineral carving is being identified, and other tests are not practical. In this instance, a small scratch on the base of the carving may be condoned. Another occasion when a hardness test might be applied with care is when it is used as a test for diamond. Diamond is the only gemstone which will scratch corundum, and in this case the test is confirmatory.

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2. Webster, R., *Practical Gemmology, 6th edn, NAG Press Ltd. (1978)*
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2 Preparation and Handling of Gemstones

Cleaning methods. Ultrasonic baths. Tweezers and scoops. Stone papers.

Before attempting to identify a gemstone, whether by inspection or by means of tests, it is most important to ensure that the stone is clean. With an unmounted stone, this can be done fairly simply by rubbing it in a lint-free cloth, preceded where necessary by a soak in a detergent solution. Cleaning is also necessary after a refractometer test, when any contact fluid still remaining on the stone must be removed. It is equally important to clean the stone after making a specific gravity test in heavy liquids.

With polished diamonds, particularly when an assessment is being made of the gem's clarity (the presence of internal flaws and inclusions), it is essential that there are no particles of dust, etc, on any of the facets, as these can cause false conclusions. The affinity of diamond for grease is another problem, as this can often be picked up from the fingers during handling. Diamond graders usually dip the diamond in a small pot of degreasing fluid (such as carbon tetrachloride) and then polish the stone in a piece of chamois leather. Packs of six highly absorbent lint-free gem cleaning cloths are available from Gem Instruments Corporation. The cloths are made from closed-loop material and are washable ($8.50 per pack, see note on page 21). Disposable lint-free cloths are also available from Hans-Günter Schneider ($3.75).

A special non-flammable liquid for removing oil, grease, etc, from gemstones is available from Gemmological Instruments Ltd. This liquid, which is called 'Rayclean', dries off rapidly without leaving residues (250 ml, $4.00).

ULTRASONIC BATHS

Mounted stones can be much more difficult to clean than unmounted ones, as the underside of the gem is made relatively inaccessible by the mount. A considerable quantity of dirt and grease can accumulate in this region, and this can be difficult to dislodge.

One of the most efficient methods of cleaning a mounted stone is to use an ultrasonic bath. This consists of a container, or tank, for the cleaning fluid, and a means of vibrating the tank at an ultrasonic frequency (in the region of 50 000–100 000 Hz). The mechanism of cleaning brought about by vibrating the cleaning fluid in this manner is called 'cavitation'. This is the creation of thousands of tiny cavities or bubbles in the liquid by the ultrasonic vibrations. When these bubbles collapse, or implode, they release enough energy to dislodge particles of dirt, even when these are trapped in inaccessible crevices.

The source of the ultrasonic energy is a slab of zirconate titanate, which is a man-made ceramic 'crystal'. This crystal possesses the piezo-electric property of being able to vibrate when an alternating voltage is applied across it (the opposite transformation occurs in a crystal pick-up cartridge in a record player. In this case, the vibrations generated by the record groove are converted into electrical impulses). The crystal, which is made in the form of a rectangular slab, is plated on two of its parallel faces, and a high frequency (50–100 kHz) voltage, usually generated by a built-in solid-state oscillator/amplifier, is applied to these plated faces. For maximum efficiency, the frequency of the oscillator is tuned to the resonant frequency of the system and because this changes with the amount of liquid in the tank and the loading of the tank, this tuning is usually made automatic. The crystal is generally mounted between the base of the tank and the baseplate of the unit, so that the vibrating faces of the crystal flex the bottom of the tank.

Various cleaning fluids can be used in the tank, and some ultrasonic equipment manufacturers often specify their own brands, which for jewellery purposes may take the form of a detergent plus ammonia. The ultrasonic baths are usually provided with a mesh basket or similar open-work device so that the articles to be cleaned can be easily lowered into, and withdrawn from, the tank.

Care should be exercised when cleaning a gemstone ultrasonically, particularly if the stone contains stress flaws (which may be visible on a polariscope, see Chapter 5), as the ultrasonic energy could release these stresses and result in damage to the stone (this warning applies equally to the application of high levels of energy in the form of light when irradiating a stone for spectroscopic examination). Shock sensitive stones such as emerald and strontium titanate should never be cleaned in an ultrasonic bath. It is also unwise to attempt to clean a porous mineral in an ultrasonic bath. This applies particularly to natural opal and synthetic opal, which will change their appearance temporarily even when immersed in pure water.

The following paragraphs describe a selection of commercial ultrasonic cleaning baths. These include units which are suitable for cleaning relatively small items of jewellery. A list of manufacturers and suppliers is given in *Table 2.1*.

COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

Table 2.1

Manufacturers or suppliers (See Appendix A for addresses)	*Ultrasonic baths*	*Tweezers*	*Scoops*	*Stone papers*
Dawe Instruments Ltd.	●			
Hanneman		●	●	●
Orme Scientific Ltd. (Sonicor)	●			
Portescap	●			
Decon	●			
Branson/Rubin	●	● † *	●	●
Nihon Hoseki-Kizai Co. Ltd.	●	●		●
Gem Instruments Corporation		●		
Gemmological Instruments Ltd.		● *		
Frank Pike		● *	●	
Charles Cooper (Hatton Garden) Ltd.	●	● *	●	●
Hans-Günter Schneider		●	●	
Haigis		● *	●	
Charles Austin Pumps Ltd.		‡		
H. S. Walsh & Sons Ltd.	●	● *	●	●

* ¾ prong stone holder
† Potteratmaster stone holder
‡ Vacuum tweezers

Dawe Ultrasonic units

These comprise a range of tanks employing solid-state circuitry mounted on rugged printed circuit boards. The transducer is a lead zirconate titanate crystal, and this is automatically driven at the correct frequency to give optimum cleaning efficiency.

The cleaning tanks are of stainless steel and have rounded corners. The smallest unit in the range is Model 6441AE which has a tank size of 76 × 127 × 127 mm, with a capacity of 0.85 litre. The power consumption is 80 watts at 220–240 V, 50 Hz ($250).

Decon Ultrasonic cleaners (*Figure 2.1*)

The smallest unit in the Decon range is Model FS100 with a capacity of 1.5 litres, and a tank size of 100 × 238 × 135 mm. The tank is stainless steel and the case is of glass-reinforced plastic. ($490). All four models in the range are fitted with a timer. Lids and mesh baskets are available as accessories.

Figure 2.1
The smallest unit in the Decon range has a capacity of 1.5 litres (Decon Laboratories Ltd)

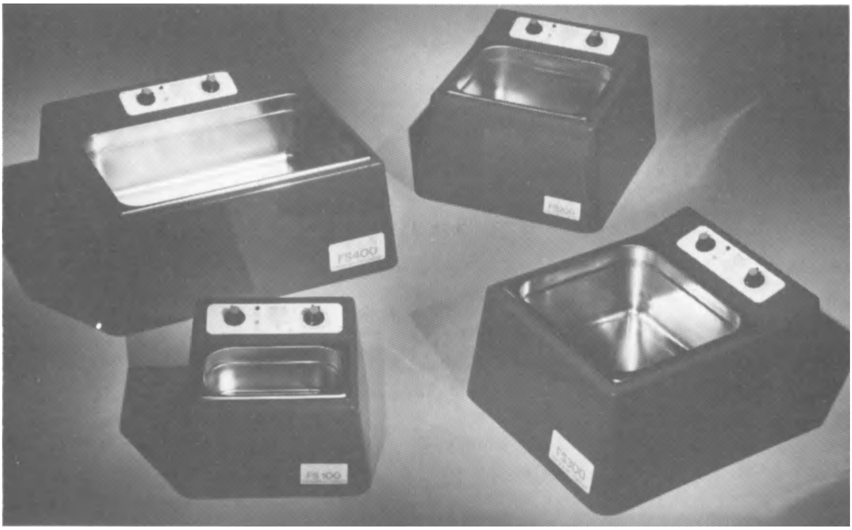
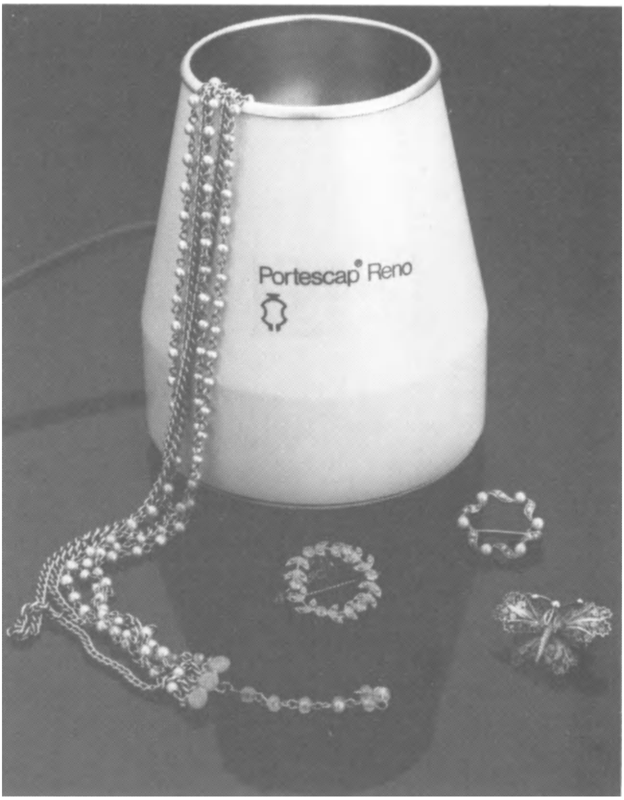


Figure 2.2
The Portescap counter-top ultrasonic cleaner, type R1, has a capacity of 0.2 litres



Portescap Ultrasonic cleaners (*Figure 2.2*)

The Portescap type R1 cleaner is a completely self-contained unit which includes a transistorized electronic drive unit, an ultrasonic transducer and a nickel-chrome steel cleaning tank with a capacity of 0.2 litre. The unit operates from 220–240 V, 50 Hz, and is adequate in size for cleaning rings, brooches and necklaces ($180).

Bransonic cleaners (R Rubin & Son)

These comprise a large range of units, the smallest of which is the Mini Branson No 3 ($138). The next smallest is Model 12, with a tank size 125 × 125 × 80 mm ($425) and Model 220, with a tank size of 225 × 130 × 100 mm ($540). Model 221 has the same size tank as the 220, but is fitted with an adjustable timer and heater ($730).

All units use lead zirconate titanate transducers and are designed for 220–240 V, 50 Hz operation. Bransonic also supply their own brand of cleaning fluid.

Sonicor Ultrasonic cleaners

The smallest Sonicor unit, Model SC50, has a 2 litre capacity and can be fitted with an optional built-in timer and heater. The unit is also provided with a multiple ring rack ($270 basic). The manufacturer, Orme Scientific Ltd., also market specialised cleaning fluids. All models operate from 220–240 V, 50 Hz.

TWEEZERS

Tweezers (or stone tongs as they are also called), are one of the basic handling tools of the gemmologist. As with chopsticks, the student may find it difficult initially to acquire the dexterity which is necessary before tweezers can be handled with confidence.

There are two basic skills to be learned with the standard tweezers; one is to be able to pick up a gem in them so that it is positionally secure, and the second is to apply just the right amount of pressure to the arms of the tweezers to retain the stone safely. Too much pressure may cause a poorly positioned stone to fly out of the tweezers.

While the beginner may feel safer with the self-closing type prong stone holder (*Figure 2.3*), this does tend to slightly mask parts of the stone under inspection, and in the case of diamond grading, may therefore affect the assessment of the gem's clarity. It may also happen that continued reliance upon this type of holder will prevent the student from ever developing the skill to use the more versatile standard tweezers.

Figure 2.3
The self-closing four-prong stone holder securely holds a gemstone without the need for finger pressure

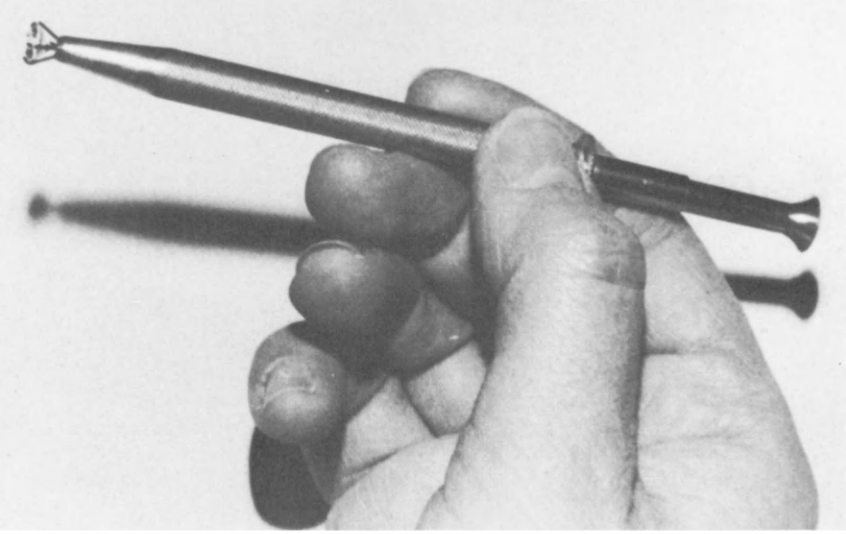
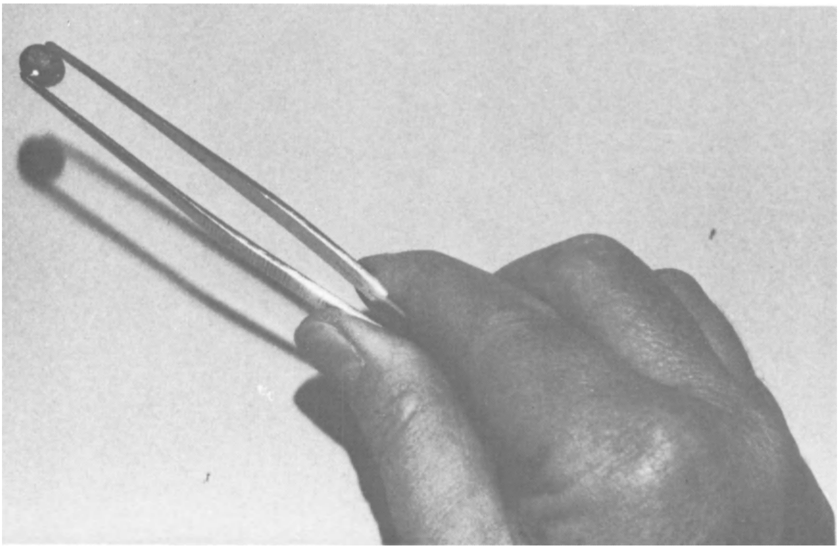


Figure 2.4
A selection of stone tweezers. The top one is combined with a small shovel, the one in the middle has a locking slide to maintain the tweezer grip without the need for finger pressure, and the two below it are crossed reversed-action types ($3 to $10)

Figure 2.5
Showing the correct method of picking up a stone, with the tips of the tweezers just over the centre line of the girdle



When choosing tweezers, the student may be bewildered by the variety which are available (*Figure 2.4*). For general gemmological use, it is probably best to start with a pair which are about 150 mm long, and have slightly rounded (rather than pointed) tips. The inside surface of these tips should have a roughened or 'hatched' surface to give them a better grip on the stone.

The best method for picking up a stone is first to lay it, table facet down, on a flat firm surface, and to position the tweezers parallel to this surface. The stone should then be lightly gripped with the tips of the tweezers positioned just over the centre line at opposite sides of the girdle (*Figure 2.5*). As an aid to gripping the girdle of a gem more securely, a groove can be filed on the inside faces of the tips in line with the arms of the tweezers.

STONE HOLDERS

The Potteratmaster stone holder (*Figure 2.6*) provides a more exotic means of securing a stone for examination. The stone is held at three points round its girdle by small grooved rollers, which allow the stone to be rotated easily within the holder. A built-in milled wheel gives finger tip control of the rotation of the rollers. When used on its stand, the holder can also be rotated and moved laterally, allowing rapid inspection of the table and pavilion facets, and of the girdle. (Complete kits $320 and $480).

The Rayner stone holder (*Figure 2.7*) uses a small spring-loaded tweezer to secure the stone, and, as with the Potteratmaster, can also be adapted

Figure 2.6
The Potteratmaster stone holder enables the gemstone to be easily rotated, allowing rapid inspection of all facets (R. Rubin & Son)

Figure 2.7
The Rayner stone holder uses spring-loaded jaws. If the base is removed the holder can be plugged into the clip hole on a microscope stage (Gemmological Instruments Ltd)

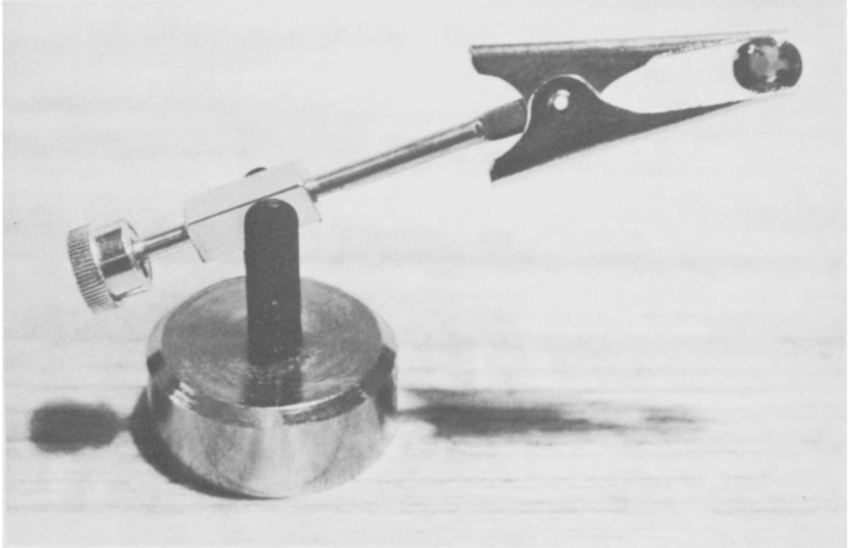
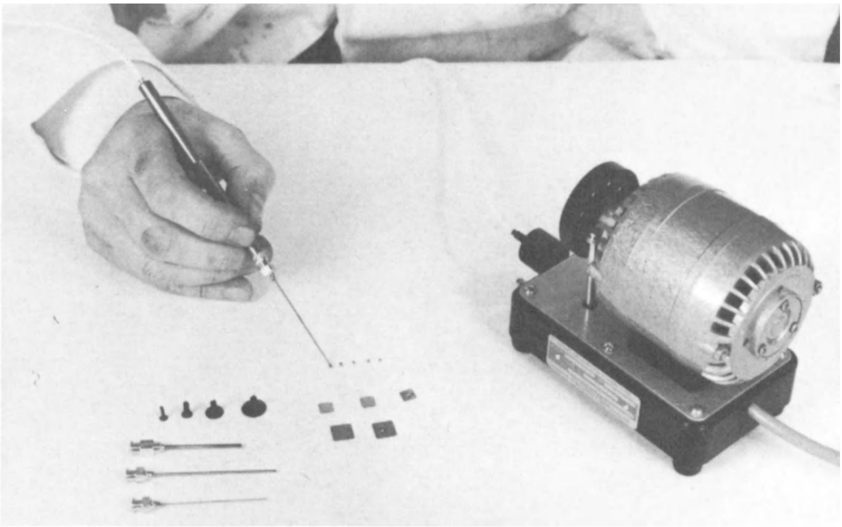


Figure 2.8
Vacuum pick up tweezers made by Charles Austin Pumps Ltd. Suction is applied to the pick up nozzle by placing a finger over a hole in the body of the probe. The range of suction pick up nozzles is shown at the bottom left corner (Charles Austin Pumps Ltd.)



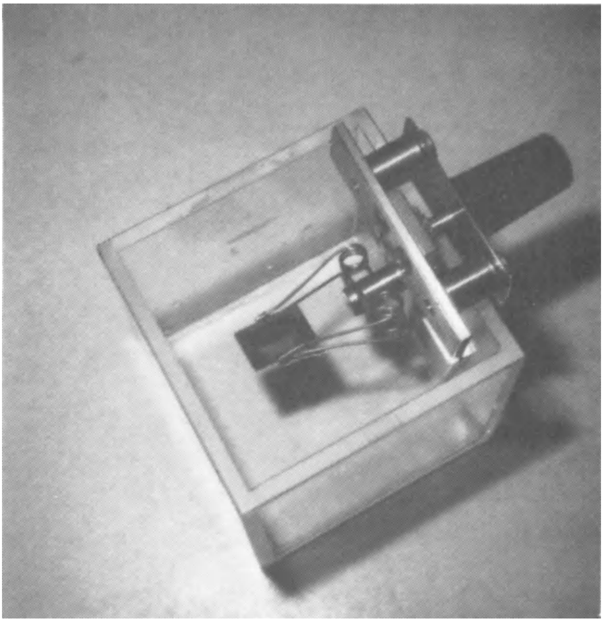
for use on a microscope. In this configuration, the base of the stone holder is removed, and the holder's mounting stem is inserted in the stage clip hole of the microscope. ($38).

Perhaps the most unusual type of stone handling device is the vacuum tweezer made by Charles Austin Pumps Ltd. (*Figure 2.8*). This was originally developed for the watchmaking and semiconductor industries, but has occasionally been used for handling gemstones. It consists of a small diaphragm-type pump which is coupled to a probe. The probe is supplied with a variety of pickup nozzles so that the most appropriate shape and size can be chosen. Vacuum is applied to the business end of the probe by simply placing a finger over a small hole in the body of the probe. When the hole is uncovered, it by-passes the nozzle and 'leaks' the vacuum away from it.

After a little practice, a stone can safely be picked up in any position. As with the standard tweezers, however, finger pressure has to be applied (in this case to the hole in the probe) all the time the stone is being inspected, although it is of course possible to tape over the hole when it is required to hold a stone for lengthy periods. ($95).

Yet another unusual stone holder is marketed by Hans-Günter Schneider (*Figure 2.9*). This holder, developed by Professor K. Siess of Vienna, is designed to clip inside an immersion cell and provide rotation of a gemstone without obscuring the field of view, particularly when using a vertical-format microscope. The wire clip stone holder is rotated from an off-set control knob via two miniature crown gears. ($82).

Figure 2.9
The Hans-Günter Schneider special stone holder for use with a deep immersion cell



SCOOPS

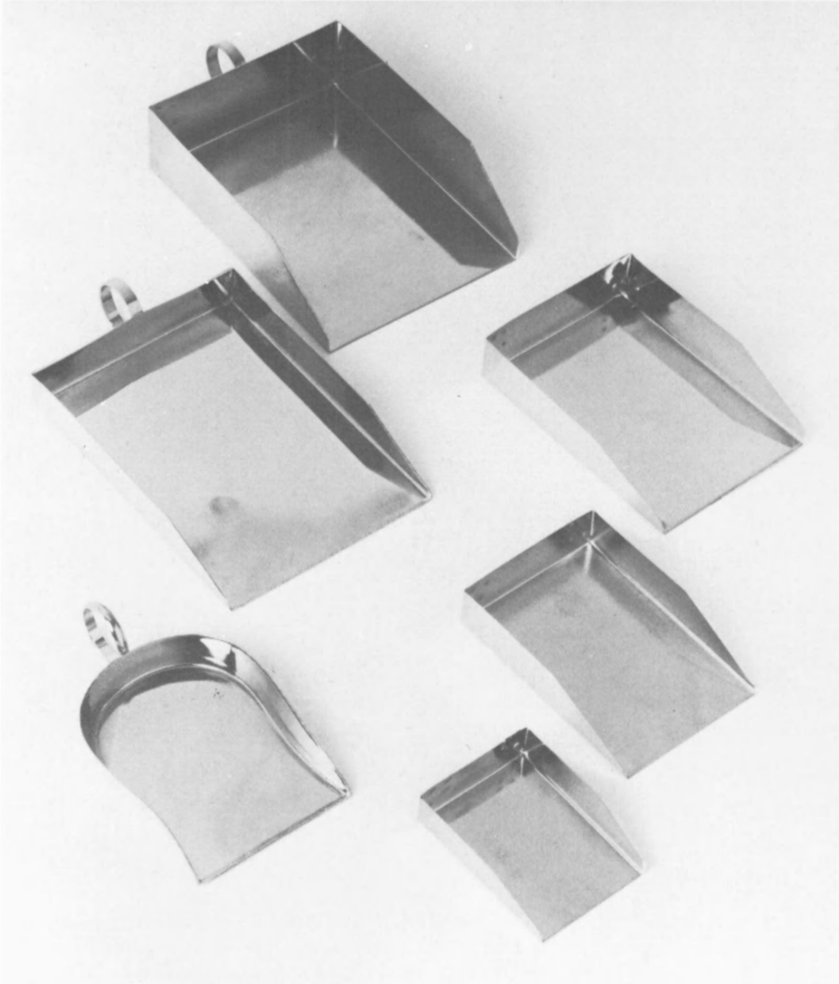
A gemstone scoop is another very useful 'tool', particularly when a number of stones are being examined, as this allows them to be gathered up in a single operation from the surface of the bench, and to be transferred speedily back to their packet. A range of small chrome plated brass scoops is available from all the leading suppliers of gemmological hand-tools and accessories.

The ultimate choice of the size and shape of scoop is essentially a personal decision, but it is as well to ensure that the selected scoop has a straight thin pickup edge so that stones can be easily gathered into it. A typical selection of scoops is shown in *Figure 2.10*. ($3 to $10).

STONE PAPERS

Stone papers, or diamond papers, are manufactured in several sizes, the most popular being the No. 2 paper, which measures approximately 4 × 2 in (102 × 51 mm) when folded, and can comfortably hold from one to fifty or more stones in the one carat size range. Stone papers are usually provided with an inner tissue lining to provide further protection for the contents, and these liners are sometimes coloured to provide an appropriate background for coloured gems.

Figure 2.10
Selection of scoops (R. Rubin & Son)



The simplicity of manufacture of the stone paper is the first thing about it which becomes apparent on inspection. This makes it possible for the gemmologist or jeweller to fold up his own papers should he need a fresh supply in a hurry (*Figure 2.11*). If the paper is unfolded until only the left and the bottom flaps are still in position, it can be partially opened to form a 'poke'. The paper can now be held in the left hand, with the bottom corner of the poke pointing downwards, and stones can be readily emptied into it from a scoop (*Figure 2.12*). Similarly, while still holding the packet in this fashion, stones can be easily poured out of the right-hand end of the open packet onto the bench, or into a scoop.

Figure 2.11
Dimensions and folding sequence for making a No. 2 size stone paper

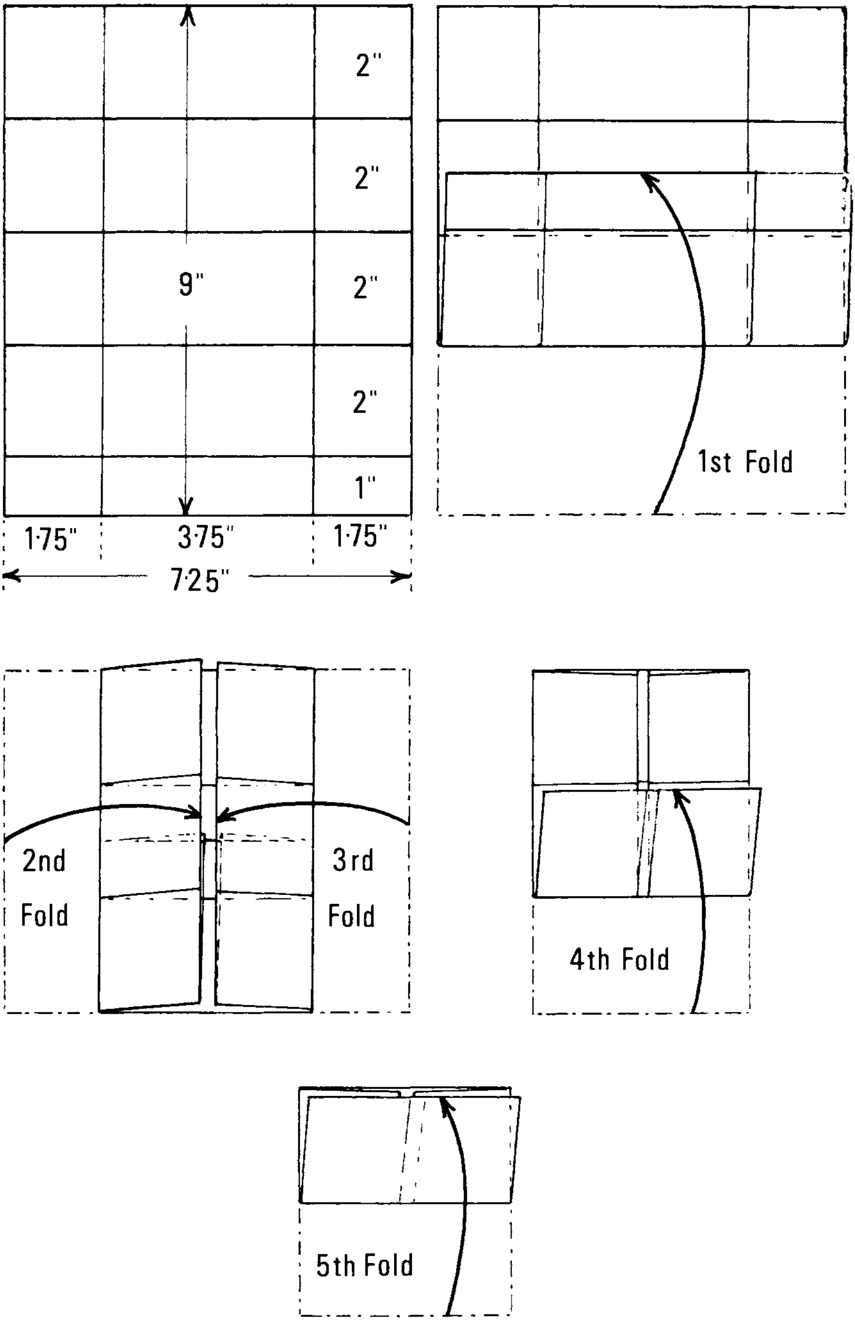
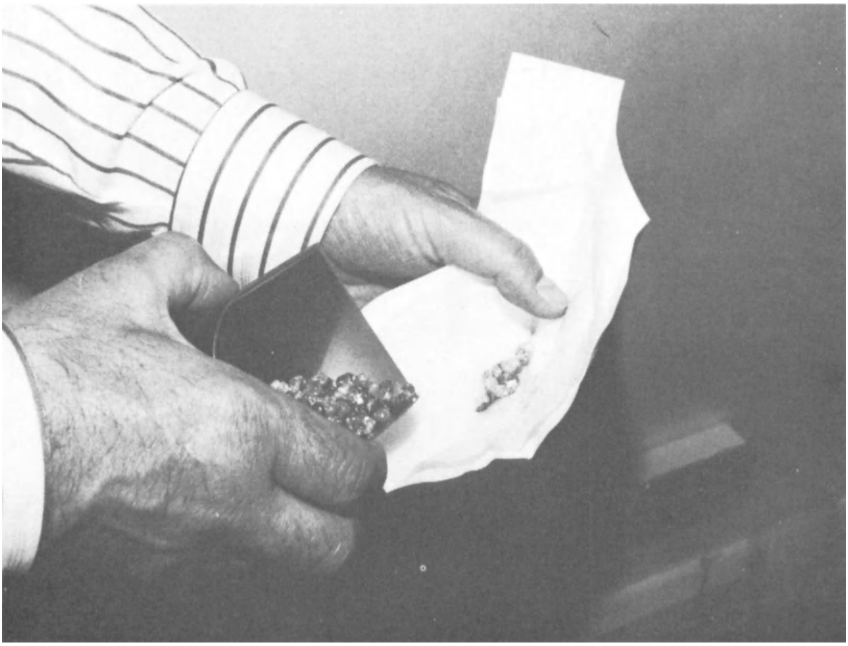


Figure 2.12
Method of holding a stone paper in the open position to receive gemstones from a scoop (see text)



Alternative packages for stones usually suffer from the disadvantages of a limited opening. The sealable plastic packet with the interlocking ribbed top is generally unsatisfactory as stones tend to be restricted by the ribs when being emptied out. However, the Nikon Hoseki-Kizai Co. Ltd., has a small transparent plastic wallet with flap (and record card) for individual diamonds called a Diamond File ($26 per pack of 100).

3 Inspection Aids

Hand lenses. Head loupes. Microscopes and attachments. Microphotography. Inspection lamps.

The hand-held lens, or hand loupe, is perhaps the most frequently used item of the gemmologist's equipment. With experience, many gemstones can be positively identified by the careful inspection of internal and surface features. It is therfore important when purchasing a lens to choose a high quality one having the correct magnification.

The most useful magnification factor is 10×, as this is sufficient to reveal most of a gemstone's identifying features. Lenses having a 25× magnification are available, but their focus is rather critical and the field of view limited, making them more difficult to use. It should also be remembered that the focal length, or working distance, between the loupe and the gemstone diminishes as the magnification increases. As it would be impossible to avoid image distortion and colour fringing if the 10× hand loupe were made using only a single lens, all high quality loupes use compound lenses, consisting generally of three lens elements.

These lenses are called 'Triplets', and are corrected for both chromatic and spherical aberration. Chromatic aberration, or distortion, causes colour fringes to be produced round an image as the result of the optical dispersion of the glass used in the lens. It is corrected by making the lens in two sections, each having a different dispersion. One lens is a bi-convex and the other is a bi-concave. Because of the different dispersion of the two lenses, all the colour component rays in white light can be brought to a common focus. Spherical aberration, which occurs in strongly curved lenses, results in the focus of rays passing through the edges of the lens lying closer to the lens than the focus of those rays which pass through the centre of the lens. The resulting image has a hazy circumference and may be distorted. To correct this, the single lens is replaced by lenses of various radii. An apochromatic lens is one which has been corrected for both chromatic and spherical aberration.

Even between high quality triplet hand lenses of the same magnification there can be differences in the field of view, and for an instrument which will be in constant use, the final choice may be for a loupe with a widefield lens.

The student gemmologist may experience some difficulty, initially, in the use of a 10× hand lens, in that he will have to keep the gemstone, the hand lens and his head steady to maintain focus. The best way out of these difficulties is first to hold the lens close to the eye (the hand holding the

Figure 3.1
Method of holding hand lens and tweezers for maximum steadiness when inspecting a gemstone

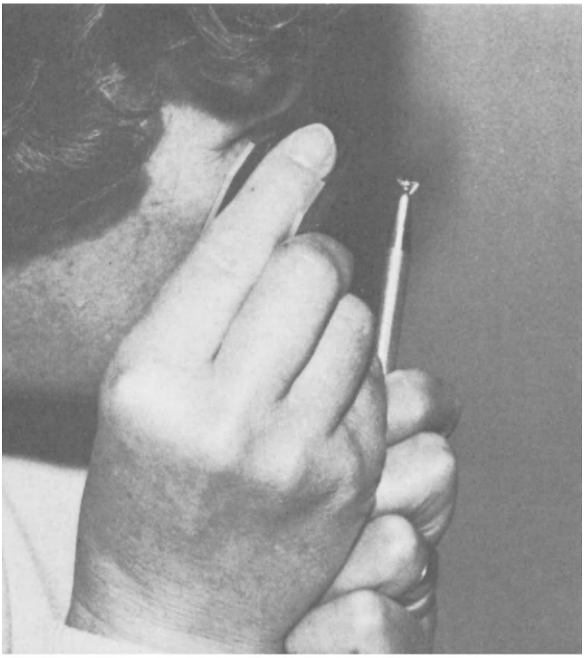
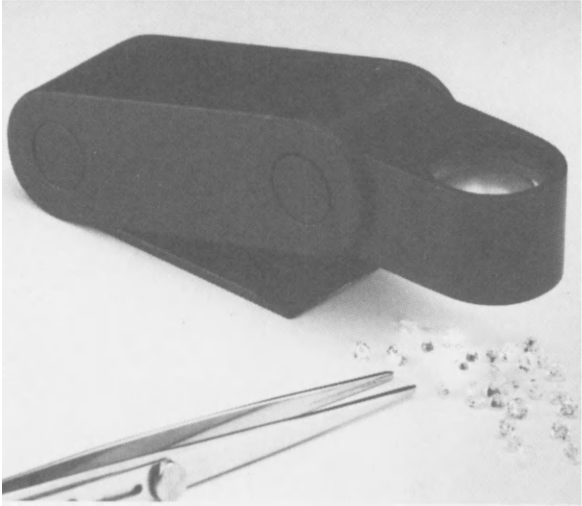


Figure 3.2
A widefield hand lens whose cover can be used as a variable height stand (GfD)



lens can be steadied against the cheek if necessary), and then to position the gemstone, held in tweezers with the other hand, for correct focus. Wavering of the hand holding the tweezers can then be prevented by resting it against the wrist of the hand holding the lens (*Figure 3.1*). If spectacles are worn, the lens should be held in contact with them.

With all loupes, illumination of the stone under inspection plays an important part. The lamp used to illuminate the stone should be adjusted

Figure 3.3
Krüss hand loupes: the lower one has a hinged supplementary lens giving a choice of 10×, 20× or 28× magnification

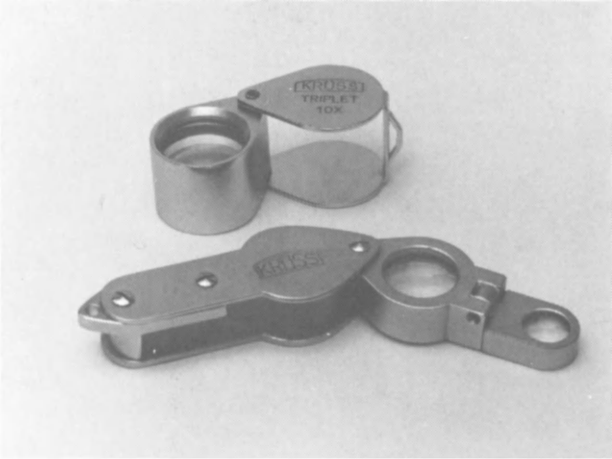
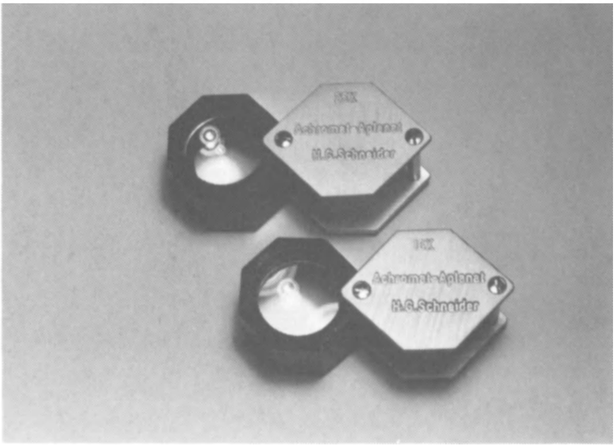


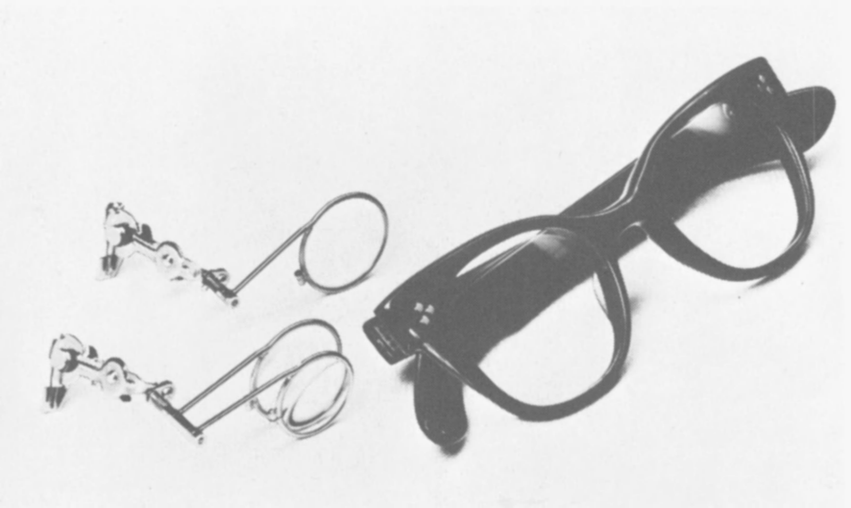
Figure 3.4
In addition to a 10× hand loupe, Hans-Günter Schneider manufacture 18× and 25× versions



so as to direct light into the side of the gem. Any internal features of the gem will then appear brightly visible against a relatively dark background. One hand loupe (the M80 by P. W. Allen & Co) has an 8× magnification and its own built-in battery-operated source of incident illumination. ($60). Another version is the GfD Profi-Loupe (*Figure 3.2*). This is a widefield 10× hand lens with a hinged cover which can be used as an adjustable-height stand ($109).

A variety of more conventional hand loupes is available, and some of these are fitted with supplementary lenses to give a choice of magnifying powers (*Figure 3.3*). As well as 10× widefield lenses ($68), 18× and 25× versions are available from Hans-Günter Schneider (*Figure 3.4*) ($80). At these relatively high magnifications, some colour fringing is noticeable outside the central third of the lens diameter. Although there is a more restricted field of view, the wide angle lens reduces this disadvantage to a tolerable level.

Figure 3.5
The Behr spectacle loupe is available in a range of single lens and double lens versions from 2× to 10× magnification



One interesting adaptation of the hand loupe, for use where long periods are to be spent on close inspection, is the Behr spectacle loupe (*Figure* 3.5). This is clamped to the side of the spectacles, and in the single lens versions is available in magnifications of from 2× to 10×. In the double lens versions, the individual lens pairs are available in magnifications of 3–5×, 3.3–5×, 4–5×, 4–7× and 5–10× (from $10). The Opticaid, a clip-on binocular spectacle loupe, is available in magnifications of 1.75×, 2.25× and 2.75× from the Rayner Optical Company ($29).

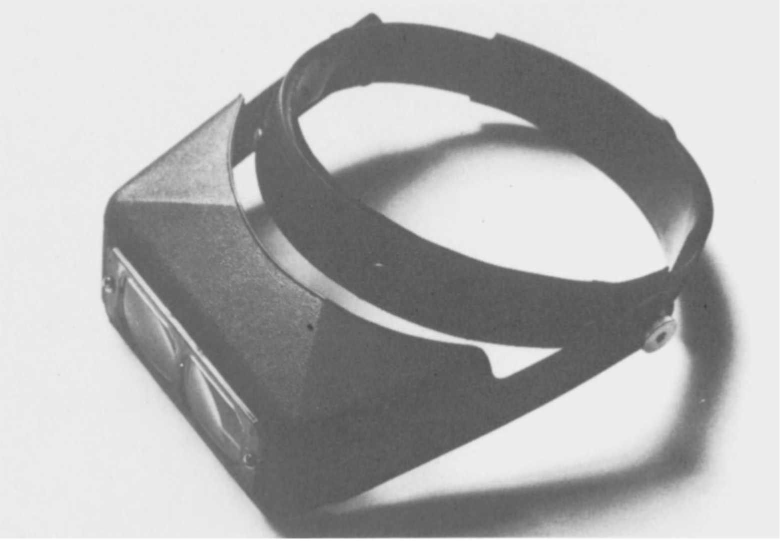
HEAD LOUPES

The Optivisor head loupe (*Figure* 3.6 $39) and a head loupe version of the Rayner Opticaid ($25) represent another solution which provides magnification while leaving the hand free. This has the added advantage of allowing binocular vision. Like the spectacle loupe, head loupes can be obtained in a range of magnifications. The lens assembly can be pivoted independently of the head band to give the most comfortable viewing angle, or it can be tilted up above the head when not in use.

MICROSCOPES AND ATTACHMENTS

When magnification, mechanical stability or illumination become limiting factors in the use of a hand or a head loupe, we must turn to the microscope. For many gemmologists this is, in any case, the preferred

Figure 3.6
The Optivisor head loupe made by the Donegan Optical Co. Inc. (R. Rubin & Son)



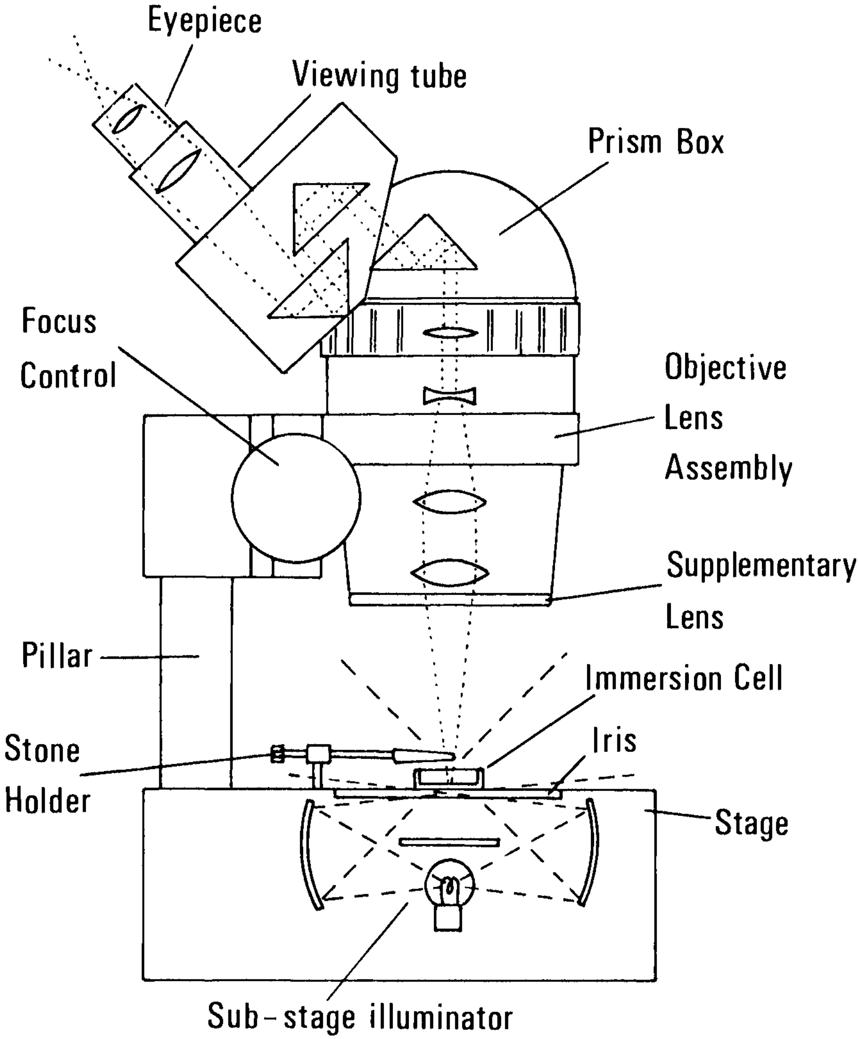
instrument. It has been said, with some justification, that gemmological analysis rests on the trio of instruments formed by the microscope, the refractometer and the spectroscope.

Particularly as a result of the trend towards binocular microscopes, the period of time that can be spent, without strain, in exploring the interior of a gemstone has made the microscope a valuable diagnostic tool. Although it is used in the identification of natural gemstones by revealing their characteristic inclusions, perhaps its most useful function is in distinguishing between synthethic and natural gems, and in detecting 'fakes' or imitation gems.

The diagram in *Figure 3.7* of a standard stereo microscope will serve to identify some of the components which are mentioned in the following descriptions of commercial models. As with the hand lens, there are two important features of a microscope which must be considered; the field of view and the working distance. The greater the magnification of the microscope, the smaller will be the field of view and the working distance. In addition, the depth of focus (i.e. the depth over which the image is within focus when looking into a gem) becomes smaller as the magnification is increased. For these reasons, the maximum magnification which is practical to use for gemmological work is in the region of 60× to 80×, with the majority of work being done in the region of 15× to 30×. Microscopes which are used for grading polished diamonds into clarity classifications must have the specified magnification of 10×.

While the majority of modern microscopes are of the binocular type, these can be divided into those which have a single objective lens system whose image is shared between the two eyepieces, and the more

Figure 3.7
Sketch showing the components and ray path for one half of a typical stereo microscope. The illuminator in the sub-stage assembly is set for dark-field work.



expensive stereo microscopes which have two objective lens systems each coupled to its respective eyepiece. There are two basic types of stereo microscope, one using the Greenough system with two converging sets of optics, and the more expensive combined-objective system with two paralleled optical systems.

Many microscopes are now designed with a zoom objective lens system which gives a stepless range of magnification. While a zoom facility on a microscope may sound attractive, it is not necessarily always the best choice, as compromises in the design of a zoom lens may result in a performance inferior to that of a turret lens system. For comparative work, where dimensions are important, the known fixed magnifications of the multi-objective turret lens may also make it preferable to the stepless magnification range of a zoom system. Some zoom microscopes provide click stops at specific magnifications.

Illumination and magnification

Apart from the simplest of monocular models, most microscopes are provided with a built-in means of illuminating the specimen on the stage. This can be as basic as a lamp and condenser lens assembly under the stage, with an iris control to vary the area of illumination. In the more sophisticated models, the choice of incident, light-field, or dark-field illumination is provided, the latter two being contained in the substage lamp assembly. With light-field illumination, light is transmitted upwards through the specimen and into the objective of the microscope. With dark-field illumination, the light is directed into the gem from the sides, and there is no direct light path between the lamp and the objective. Dark-field illumination is generally the preferred method for gemmological work as it gives better contrast.

Many microscope manufacturers design their instruments on a modular basis, the various optical heads, stands, sources of illumination and accessories being interchangeable (e.g. Wild Heerbrugg, Kyowa). This enables each microscope to be assembled to meet the needs of a variety of applications. Microscope accessories are equally numerous, and include polarising filters, colour and neutral density filters, camera attachments, tracing attachments, projection screens, stands, and manually and electrically operated X and Y index stages. Of these accessories, one of the most useful for gemmological work is the polarising filter which can be used to reveal internal stresses and strains (in the form of anomalous birefringence) and to improve contrast in gemstones.

The overall image magnification of a microscope is arrived at by multiplying the magnification of the eyepiece by the magnification of the objective. If a supplementary or adaptor lens is fitted to the objective, the overall magnification factor must then be multiplied by the magnification figure for this extra lens. The working distance between the objective and the specimen, and the diameter of the field of view are both reduced in direct proportion to the increase in objective power. For example, if the 10× objective of a microscope having an overall magnification of 50×, a working distance of 20 mm and a field of view of 5 mm, is replaced with a 20× objective, the overall magnification will become 100×, the working distance will become 10 mm, and the field of view will become 2.5 mm. Changing the power of the eyepiece similarly reduces the field of view, but not the working distance.

To avoid the possibility of lowering the objective onto the specimen when focusing, and thus scratching the lens, it is good practice always to start with the objective just clear of the specimen, and to find the initial focus setting by adjusting the objective away from the specimen. Focusing is more easily carried out by using the lowest magnification power of the microscope and then increasing this as required.

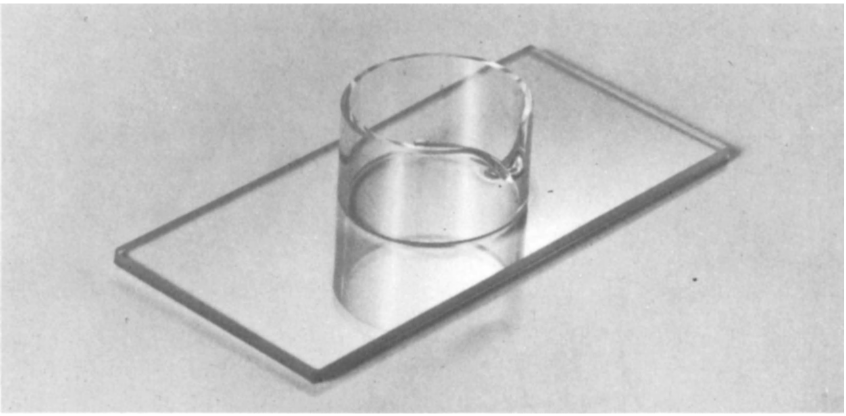
If the microscope is provided with its own integral light source, it should be set for dark-field illumination. If only light-field illumination is provided, the iris control should be set so that the minimum of light escapes round the sides of the stone. If only external illumination is available, this should be adjusted so that the light is directed into the side of the stone.

When inspecting the interior of a gemstone, particularly when using the higher magnifications, trouble is often experienced because the illuminating light is reflected back from the facets of the stone, thus preventing sufficient light from entering the stone to illuminate it adequately. Dark-field illumination, or co-axial illumination injected through the lens system via a beam splitter, often overcomes this problem, but when difficulties are experienced with facet reflections, these can be eliminated by placing the gemstone in a glass immersion cell (*Figure 3.8*) and filling the cell with a liquid having a refractive index somewhere near to that of the stone. If the refractive index of the liquid is close to that of the gemstone, a colourless stone will virtually disappear, as no reflection can occur at the interface between the stone facets and the liquid. In practice, the liquid does not have to match the refractive index of the gemstone, and even immersing the stone in water reduces reflections. As gemmologists usually have a selection of heavy liquids to hand for specific gravity tests, it is convenient to use these as immersion fluids. The following three heavy liquids are listed together with their refractive indices:

Bromoform	1.59
Monobromonaphthalene	1.66
Methylene Iodide	1.74

In some commercial microscopes, the lens assembly has been designed so that the light path of the objective is horizontal. This is done to facilitate

Figure 3.8
An immersion cell (Gemmological Instruments Ltd.)



the use of a deep immersion cell, which allows the stone holder to be inserted into the cell vertically (in the conventional upright microscope, the height of the cell is limited).

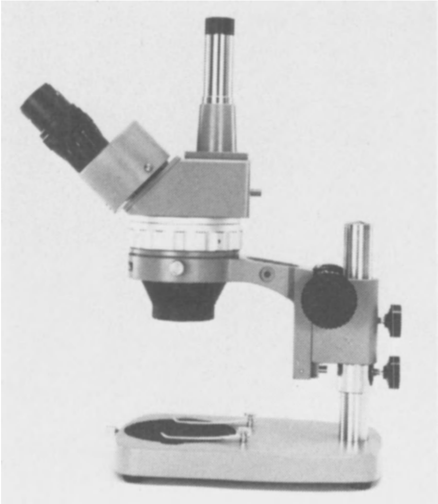
The following paragraphs describe and illustrate a selection of commercial microscopes which are suitable for gemmological use. Manufacturers and suppliers are listed in Table 3.1.

Table 3.1

Manufacturers or suppliers (see Appendix A for addresses)	*Hand loupes*	*Head loupes*	*Microscopes*	*Illuminated stand magnifiers*	*Inspection lamps*
American Optical/ Reichert–Jung UK					●
Bausch and Lomb	●		●		
Kyowa/Finlay Microvision			●		
Gfd	●		●		
Gem Inst. Corp.	●	●	●		
Gemmological Inst. Ltd.	●		●		●
Zenith/Hodgkinson			●		
Eickhorst			● †		
Krüss	●		● †		●
Olympus/Gallenkamp Ltd./Metallurgical Services Laboratories Ltd.	●		●	●	●
Hans-Günter Schneider	●	●	● †		●
Donegan Optical Co. Inc./Rubin		●			
Frank Pike	●	●			
PBL/Auriema					●
I.V.A. Engineering Co. Ltd.					●
Rubin	●	● *	●	●	●
Wild Heerbrugg			●		
P. W. Allen	●			●	●
Prior Scientific Instruments Ltd.			●		
Zeiss			●		
Volpi/Capital UE Ltd./Huddlestone Gemmology Consultants Ltd.					●
Nihon Hoseki-Kizai Co. Ltd.	●		●		●
Gem Laboratory Inc.			●		

* Spectacle loupe
† Horizontal format microscopes

Figure 3.9
The Kyowa SDZ-STR-P trinocular stereo zoom model (Finlay microvision)



COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

Kyowa, Model SDZ-TR-P (Finlay Mocrovision Co Ltd) (*Figure 3.9*)

This is a trinocular stereo zoom instrument (6.5:1 ratio). Basic magnification range, with 10× widefield eyepieces, 7× to 45×. Working distance at 7× is 86 mm. Field of view is 33 mm. ($1730). The focusing mount has a port for an illuminator. ($82).

Supplementary lenses of 0.5×, 0.75×, 1.5× and 2× are available together with 15× and 20× widefield eyepieces. Photographic accessories for the trinocular port include mounts for a polaroid camera, a 35 mm camera or a TV camera.

Kyowa Model SDZ-AL-J (Finlay Microvision Co. Ltd)

Called the 'Stereo Jewelscope', this is a stereo zoom microscope (6.5:1 ratio). Basic magnification range, with 10× widefield eyepieces, 7× to 45×. Working distance at 7× is 86 mm. Field of view is 33 mm. The transmitted light illuminator base is fitted with a dark-field attachment, and an incident light source is also provided. A stone holder is fitted as standard. ($1400).

Supplementary lenses of 0.5, 0.75, 1.6 and 2× are available together with 15× and 20× widefield eyepieces.

Gemolite Models (Gem Instruments Corporation/Gemmological Instruments Ltd/GfD)

This range of microscopes has been designed specifically for gemmological and diamond grading work, and uses optical heads made by leading manufacturers in this field. The result is a relatively economical range of products, most of which have the necessary built-in choice of illumination and magnifications to give a good optical image for both coloured stone and diamond inspection. (See also VideoMaster adaptor in Chapter 16).

Ultima A Mk. V Gemolite

This instrument is a stereo zoom model (6:1 ratio) using American Optical optics with 10× eyepieces. Basic magnification range 10× to 60×. Working distance is 100 mm. Field of view at 10× is 24.6 mm. The illuminator is fitted with an adjustable iris, and can be switched from light-field to dark-field. An incident light source and a stone holder are fitted as standard. ($2075).

A supplementary lens of 2× is available, together with 15× and 25× eyepieces.

Ultima B Mk. V Gemolite (*Figure 3.10*)

This is a stereo zoom model (7:1 ratio) using Bausch and Lomb StereoZoom 7 optics with 10× eyepieces. Basic magnification range 10×

Figure 3.10
The Ultima B Mk V Gemolite (Gem Instruments Corporation)

to 70×. Working distance is 76 mm. Field of view at 10× is 20 mm. The light/dark-field illuminator is the same as fitted to the Ultima A Mk. V Gemolite. A stone holder is fitted as standard. ($2075).

A supplementary lens of 2× is available, together with 15× and 20× eyepieces.

Custom A Mk. V Gemolite (*Figure 3.11*)

This is a stereo zoom model (6.3:1 ratio) using American Optical Company StereoStar optics with 15× eyepieces. Basic magnification range 10× to 63×. Working distance 100 mm. Field of view at 10× is 24.6 mm. Light sources as for the Ultima A Mk. V Gemolite. A stone holder is fitted as standard. ($1775).

A supplementary lens of 2× is available, together with 10× and 25× eyepieces.

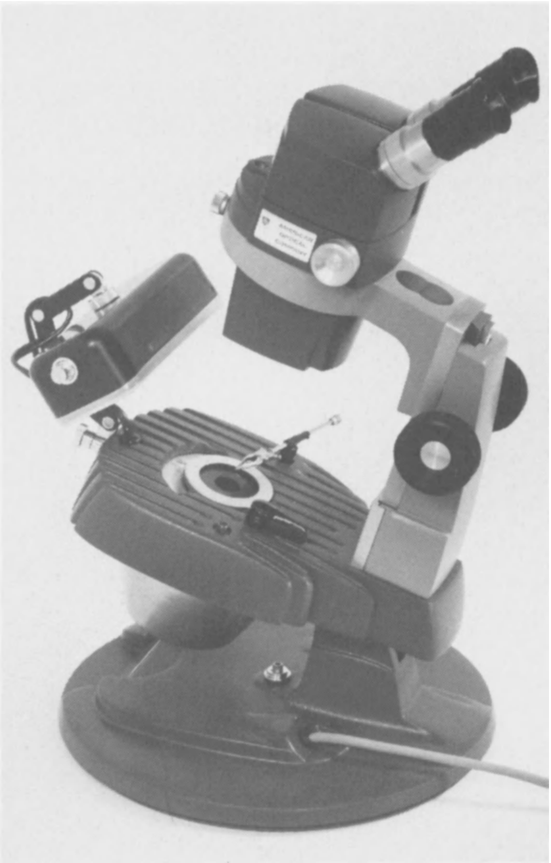


Figure 3.11
Custom A Mk V Gemolite
(Gem Instruments Corporation)

Custom B Mk. V Gemolite

This is a stereo zoom model (5:1 ratio) using Bausch and Lomb StereoZoom 5 optics with 10× eyepieces. Basic magnification range 8× to 40×. Working distance 100 mm. Field of view at 10× is 24.9 mm. Light sources are as for Ultima A Mk. V Gemolite. A stone holder is fitted as standard. ($1650).

A supplementary lens of 2× is available, together with 15× and 20× eyepieces.

Deluxe A Mk. V Gemolite

This is a more economical version of the Custom A model. It is a stereo zoom microscope (4.5:1 ratio) using American Optical Company StereoStar optics with 15× eyepieces. Basic magnification range 10× to 45×. Working distance 100 mm. Field of view at 10× is 24.6 mm. Light source as for the Ultima A Mk. V Gemolite. A stone holder is fitted as standard. ($1550).

A supplementary lens of 2× is available, together with 10× and 25× eyepieces.

Deluxe B Mk. V Gemolite

This is a more economical version of the Custom B model. It is a stereo zoom microscope (4.5:1 ratio) using Bausch and Lomb StereoZoom 4 optics with 15× eyepieces. Basic magnification range 10× to 45×. Working distance 100 mm. Field of view at 10× is 24 mm. Light sources as for the Ultima A Mk. V Gemolite. A stone holder is fitted as standard. ($1550).

A supplementary lens of 2× is available, together with 10× and 20× eyepieces.

Duo Cycloptic Gemolite

Using American Optical Company's Magni-Changer optical system, this microscope is fitted with dual optics for simultaneous viewing when teaching or selling. Fixed magnifications of 10, 15, 20, 30 and 40× using 15× eyepieces. Working distance at 10× is 100 mm. Field of view at 10× is 25 mm. Light sources as for the Ultima A Mk. V. Gemolite. A stone holder, inclusion pointer and turntable base are fitted as standard. ($2085).

A supplementary lens of 2× is available, together with 20× eyepieces.

Diamond grader

This is an economical binocular microscope designed for diamond grading and gem identification. Magnification is 10× and 30× with 10× eyepieces.

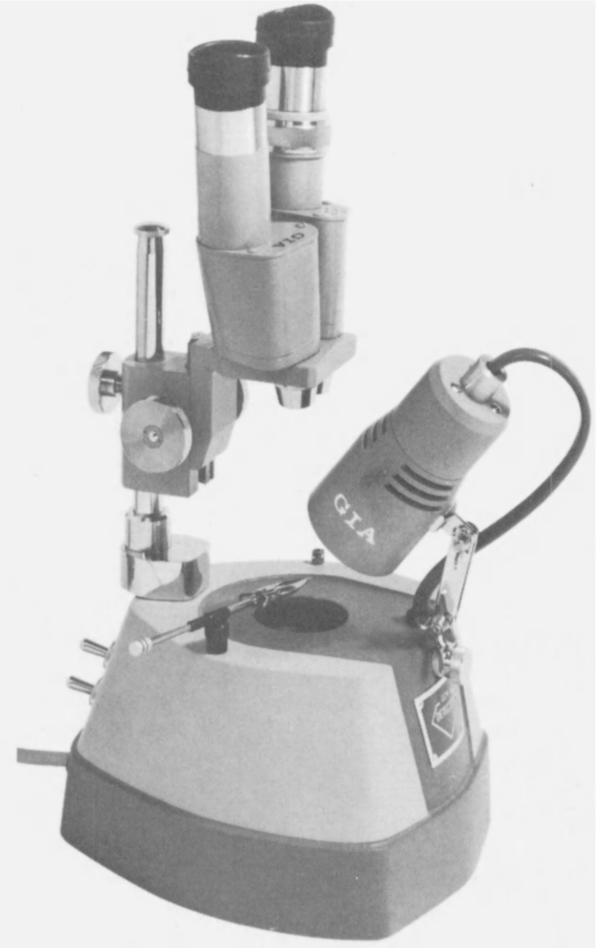
A sub-stage illuminator is fitted, and the instrument is supplied with a removable stone holder. Optional extras include an inclusion pointer, a Color Grader tray, 2× supplementary lens and 15× eyepieces. ($950)

Gem detector (*Figure 3.12*)

This is a comparatively low priced stereo microscope primarily designed for the student gemmologist. Magnification of 10× using 5× eyepieces; this can be increased to 30× with 15× eyepieces. Working distance is 75 mm. Field of view at 10× is 12 mm.

Dark-field illuminator, and an incident light source. A removable stone holder is supplied. ($495).

Figure 3.12
The gem detector (Gem Instruments Corporation)



IMMERSION MICROSCOPES

Included in the ranges of the following three German instrument companies are microscopes whose optical heads have been turned through 90 degrees to give a horizontal, rather than vertical, axis to the objective lens. This configuration is particularly useful for immersion work as it facilitates the vertical insertion and manipulation of a stone holder in a deep immersion cell without obstructing the field of view.

Some of these microscopes have been designed so that a single optical head can be fitted to either a vertical or a horizontal base, and can therefore be used both for coloured stone immersion inspection and for diamond grading purposes.

Portable microscope KA-4 (Krüss)(*Figure 3.13*)

This is a monocular-zoom horizontal microscope with a self-contained immersion cell and a stone holder. Basic magnification range is 10× to 35× using a 10× eyepiece. A 20× eyepiece is available together with a

Figure 3.13
Portable microscope KA-4 as supplied with the portable laboratory KA-4KRS (Krüss)

dichroscope eyepiece and a polariser unit. The built-in light source is battery-powered (a battery charger is available for the Ni-Cd cells). The microscope weighs 1.25 Kg and measures 40 × 300 × 80 mm. ($635). Also available for use with the KA-4 is a mains-powered (220 V, 50 Hz) illumination stand BM15. ($354).

As model KA-4KRS, the microscope can be supplied in a metal carrying case equipped as a portable laboratory (see Chapter 16).

KA-6Z Diamond stereo microscope (Krüss/GfD)*(Figure 3.14)*

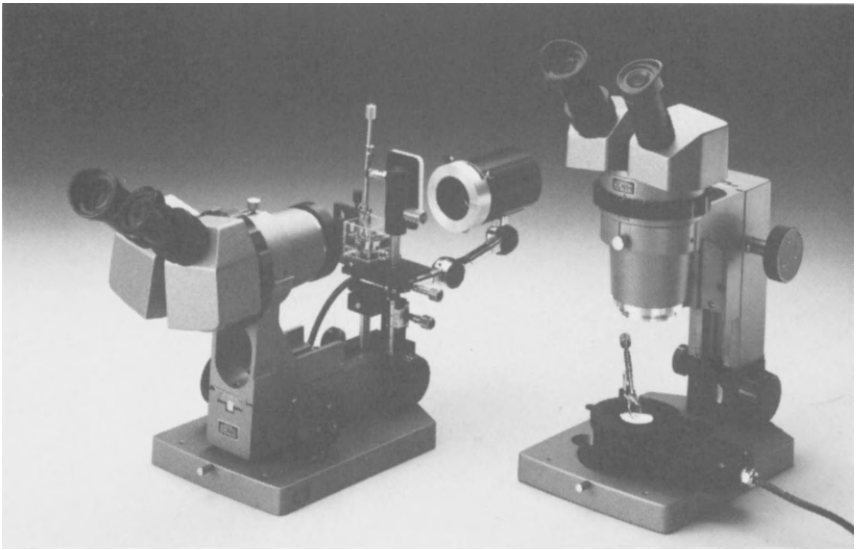
A stereo zoom microscope (4:1 ratio) having a basic magnification range of 10× to 40× with widefield eyepieces. The light source is a neon ring illuminator which can be used with iris control for dark-field work. A stone holder is fitted as standard. ($1480).

Supplementary lenses of 0.5 and 2× are available, together with 20× widefield eyepieces and a diamond-proportion eyepiece graticule.

KA-7 Diamond stereo microscope (Krüss)

This is similar in appearance to the KA-6Z, but uses a stereo optical head fitted with a lens turret giving fixed basic magnifications of 10× and 20× with 10× eyepieces. ($986). 15× and 20× widefield eyepieces are available.

Figure 3.14
(left) The KA-11; (right) The KA-6Z (Krüss)



KA-9 Gemstone and diamond stereo microscope (Krüss)

This is similar in appearance to the KA-11, but uses a stereo optical head fitted with a lens turret giving basic magnifications of 10× and 20× with 10× eyepieces. Like the KA-11 it can be used either in the horizontal mode for the immersion inspection of coloured stones, or it can be easily re-mounted on its stand for vertical use in diamond grading. A polarizing attachment is supplied as standard. ($1490). Accessories are as for the KA-6Z.

KA-11 Gemstone and diamond stereo microscope (Krüss) (*Figure 3.14*)

This is a stereo zoom microscope (4:1 ratio). Basic magnification range is 10× to 40× with widefield eyepieces. The unit can either be used in the horizontal mode for the immersion inspection of coloured stones, or can be easily re-mounted on its stand for vertical use in diamond grading. The immersion cell table is vertically and horizontally adjustable, and a glass cuvette (with polarising attachment) and stone holder are fitted as standard. The adjustable-intensity light source (with iris) can be pivoted around the gem to give light-field, dark-field and incident illumination. ($1950). Accessories are as for the KA-6Z.

KA-12 diamond measuring microscope (Krüss)

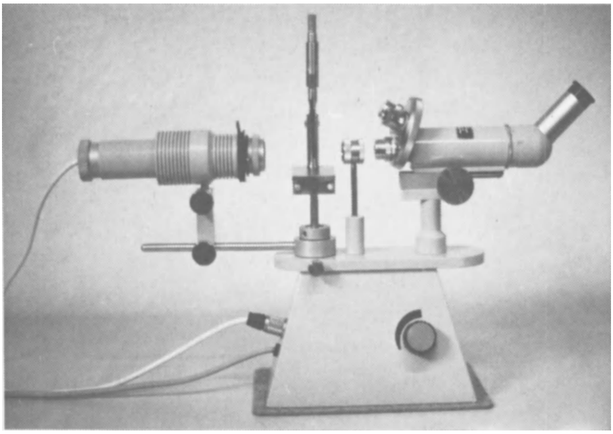
This is an improved version of the KA-6Z and includes a daylight neon ring illuminator for the provision of shadowless and transmitted illumination, a 4:1 stereo zoom head with 10× eyepieces, a vernier cross-slide adjustment for the stone holder, a diamond proportion eyepiece and a digital 'height feeler' gauge for the estimation of the depth of inclusions beneath the table facet (and the estimation of R.I.). ($3173). The digital height feeler gauge DT10 is available separately ($877).

Diamond and gem microscope DE2 (Hans-Günter Schneider)

A monocular microscope with magnifications of 10×, 17.5× and 25× using 5× eyepieces (10× and 20× eyepieces are available). The working distance at 10× is 40–65 mm. The microscope is designed with a horizontal-format objective to facilitate the use of an immersion cell.

The illuminator, with filter holder, iris and intensity control, can be pivoted radially to provide dark-field, light-field or incident illumination. A polarising attachment and a separate transformer unit for the illuminator are supplied as standard. The stage is fitted with a stone holder, and various diamond testing accessories are available. ($955).

Figure 3.15
Diamond and gem microscope DE2S (Hans-Günter Schneider)



Diamond and gem microscope DE2S (Hans-Günter Schneider)(*Figure 3.15*)

This is a version of model DE2 with the light source transformer built into the base. ($1000).

Diamond and gem microscope DE3 (Hans-Günter Schneider)

A binocular microscope with a magnification of 10×, 17.5×, 25× and 50×, using 5× eyepieces (10× and 20× eyepieces are available). The remainder of the specification is the same as for Model DE2. ($1320).

Diamond and gem microscope DE3S (Hans-Günter Schneider)

This is a version of Model DE3 which is fitted with an additional 7× objective and 25× eyepieces. ($1545).

Diamond and gem microscope SZ4 (Hans-Günter Schneider)

This is a stereo zoom microscope (4:1 ratio) using a Zeiss optical head. Basic magnification range is 10× to 40× with 10× eyepieces. The microscope is designed for use with a horizontal objective axis to facilitate the use of a deep immersion cell.

The light source (supplied with filter holder, iris adjustment and intensity control) can be pivoted radially to provide dark-field, light-field or incident illumination. The stage is fitted with a stone holder, and a polarising attachment is supplied as standard. ($2640).

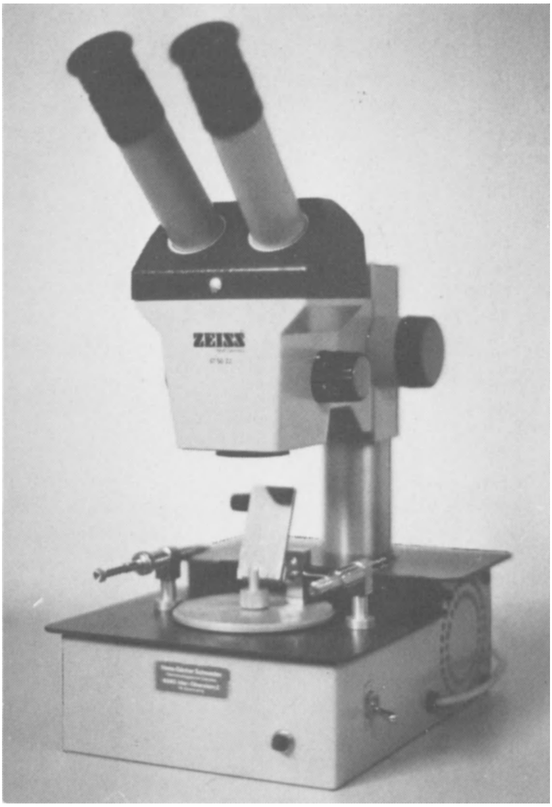


Figure 3.16
Special stereo-zoom diamond microscope with Zeiss optical equipment (Hans-Günter Schneider

Stereo-zoom diamond microscope (Hans-Günter Schneider/GfD)

(*Figure 3.16*)

This is a stereo zoom microscope (4:1 ratio) designed specifically for diamond grading and using a Zeiss optical head. Magnification range is 10× to 40× with 10× eyepieces. The base of the instrument contains a high-intensity adjustable light source which is channelled to the diamond via the central aperture in a rotatable metal stone holder (a range of holders provide for diamonds of various sizes).

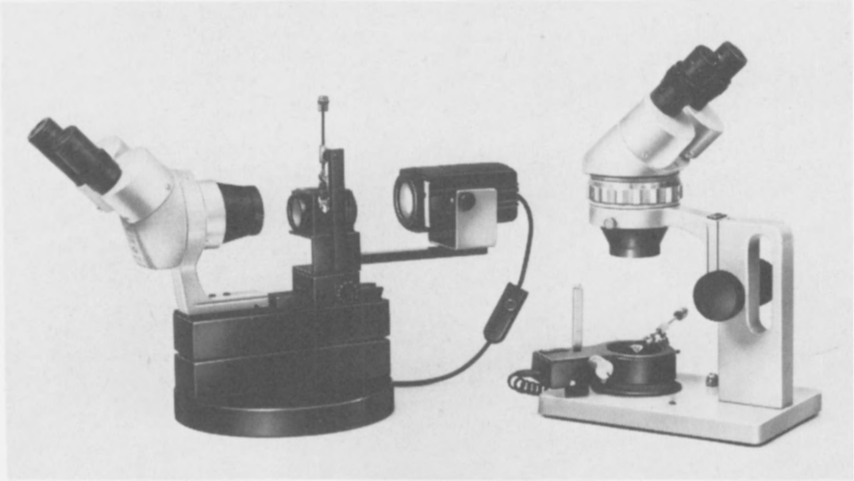
After the crown of the diamond has been inspected, the holder is moved forward, and an angled mirror is used to provide a side view of the diamond's girdle. The diamond can then be turned onto its table facet for inspection of the pavilion.

An eyepiece graticule is available for measuring the size of inclusions, and a dial gauge can be fitted for estimating the depth at which the inclusion lies beneath the table facet. The microscope can operate from 100 to 240 V mains supply via an automatic voltage converter. Two stone holders are provided as standard to secure fancy cuts and mounted stones. ($3636).

Horizontal gem immersion stands (Eickhorst)

There are two basic immersion stands in the Eickhorst range, each one complete with glass immersion cell, adjustable immersion platform and stone holder, a polarising attachment and a radially-pivotable light source. Both these stands can be fitted with a variety of optical heads. Model HDF-W ($650) is illustrated in *Figure 3.17*. Model GIS-W ($1210) uses the Gemmodule type construction. Optical heads available for these stands are as follows:

Figure 3.17
(left) Horizontal immersion stand HDF-W with choice of optic head; (right) Diamond grading stand SDG-W with choice of optic head. (Eickhorst)



Stereozoom-Optical System – Basic magnification range 7× to 45× with 10× eyepieces. Field of view at 10× is 23 mm. Supplementary 2× lens and 15× and 20× eyepieces are available. ($1240).

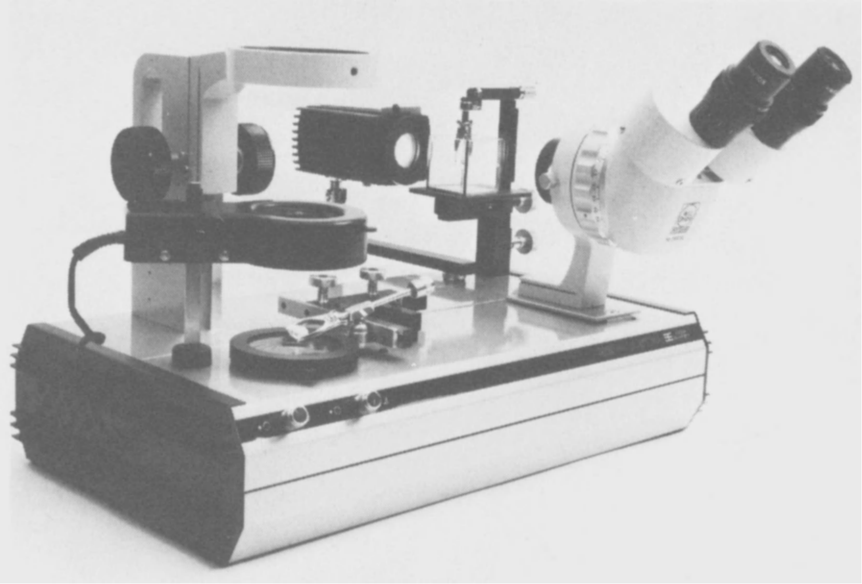
Stereozoom-Optical Trinocular System – As for the Stereo-Optical System, but with a port for camera attachments. ($1518).

Stereo-Optical System – Fixed turret-lens magnifications of 10× and 30× with 10× eyepieces. Field of view at 10× is 23 mm. 20× eyepieces available. ($723).

Diamond grading stand (Eickhorst)(*Figure 3.17*)

This is a vertical stand Model SDG-W ($482) which can be fitted with any of the three optical heads listed for the Horizontal Gem Immersion Stands. It is fitted with a ring-type neon illuminator which can be adjusted vertically to give dark-field or incident illumination.

Figure 3.18
Gemmaster dual-purpose microscope base with choice of optic head (Eickhorst)



Gemmaster microscope base (Eickhorst)(*Figure 3.18*)

This is a combination stand with provision for mounting an optical head either horizontally for the immersion inspection of coloured stones or vertically for diamond grading. Two independent illumination systems are provided, a radially-pivotable one for immersion work, and a ring-type neon for diamond grading. ($2795).

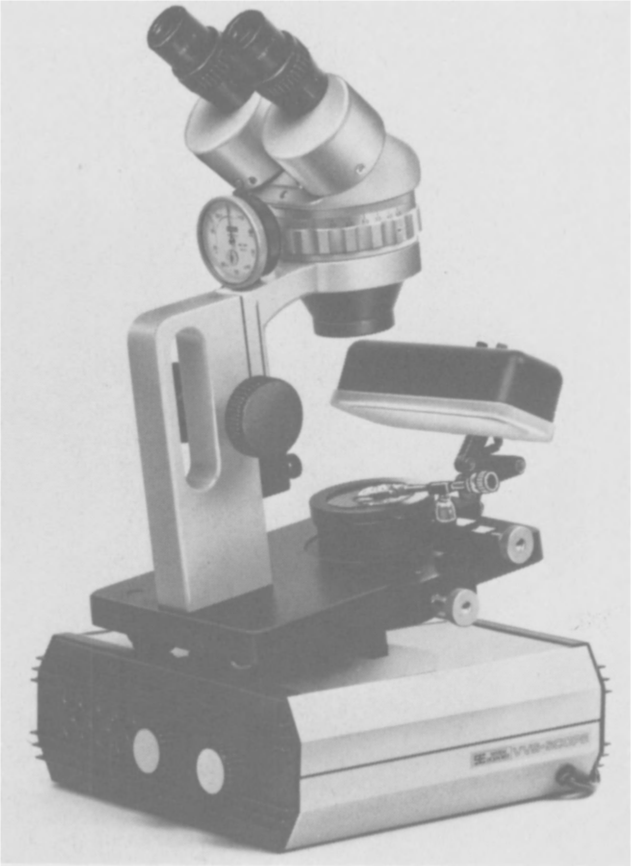
The stand can be fitted with either of the Stereozoom heads listed under the 'Horizontal Gem Stands'. Accessories include a proportion analysing eyepiece, an eyepiece graticule for measuring the size of inclusions, a dial gauge for estimating the depth of an inclusion beneath the surface of the table, and an XY cross-slide stage for the stone holder. (See also the TV camera attachment in Chapter 16).

VVS-Scope Base (Eickhorst)(*Figure 3.19*)

This is a base unit developed specially for diamond grading. An adjustable high-intensity light source is fitted in the base of the unit and is coupled to the dark-field illuminator ring by a glass-fibre light guide ($1423).

The top mounting platform can be tilted on its base for comfortable viewing, and the stand can be fitted with either of the Stereozoom heads listed under Horizontal Gem Immersion Stands.

Figure 3.19
VVS Scope base with choice of optic head (Eickhorst)

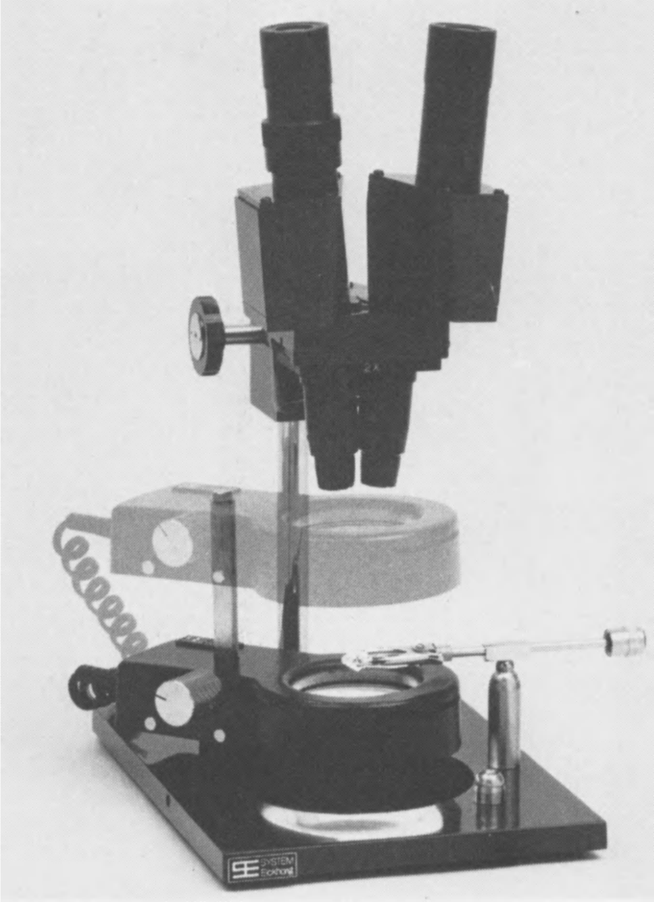


Accessories include a proportion analysing eyepiece, an eyepiece graticule for measuring the size of inclusions, a dial gauge for estimating the depth of an inclusion beneath the surface of the table, an incident light source and two XY cross-slides for the stone holder.

Mini-DiamondScope (Eickhorst)(*Figure 3.20*)

This is a compact stereo microscope with a basic magnification of 10× using 10× eyepieces. It is fitted on a plain stand with a stone holder and a neon ring-illuminator whose height can be adjusted to give incident or dark-field illumination. ($454). Available as optional extras are a 2× objective adaptor ($58), a 3× objective adaptor ($77) and 20× eyepieces ($104).

Figure 3.20
The Mini-Diamond Scope (Eickhorst)



Zenith Biolam (A. Hodgkinson)

This is a Russian-built monocular microscope with a twin-objective turret lens giving basic magnifications of 24.5× and 56× with a 7× eyepiece. A 15× eyepiece is also provided to give magnifications of 52.5× and 120×. ($244). A 'Demonstrator' attachment allows for simultaneous focused viewing by two people. ($120).

Olympus JM (Gallenkamp and Co/Metallurgical Services Laboratories Ltd)*(Figure 3.21)*

This is a stero zoom microscope (5.7:1 ratio), with a magnification range of 7× to 40× using 10× eyepieces (20× eyepieces are also provided). The

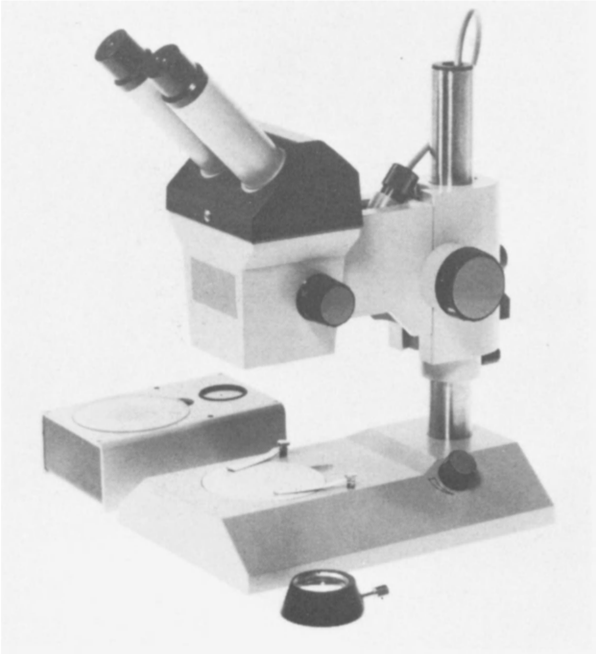
Figure 3.21
Jewellers Microscope model JM by Olympus (Gallenkamp Ltd.)

working distance is 88 mm. The field of view at 7× is 31.4 mm. Supplementary lenses of 0.5×, 0.75×, 1.5× and 2× are available as are 15× eyepieces. Dark-field and light-field illumination is provided with iris control. A stone holder and an incident light illuminator is fitted. ($1625). A trinocular version JM-Tr is available with a port for photographic attachments. ($2049). A wide range of other microscopes and accessories are also available.

Zeiss DV4 (Carl Zeiss (Oberkochen) Ltd)(*Figure 3.22*)

This is a stereo zoom microscope (4:1 ratio) with built-in zoom stops at standard magnification factors. Basic magnification (with 4× eyepieces) is 4× to 16×. Eyepieces of 10× and 25× are available, extending the zoom range to 100×. Widefield eyepieces of 10× and 16× can also be supplied. Supplementary lenses of 0.5× and 2× can be provided. ($2000).

Figure 3.22
Stereo zoom microscope DV4 (Zeiss)



A choice of two stands is available; stand L (see *Figure 3.22*) has an integral mains transformer and intensity control for a halogen lamp incident light illuminator, which is fitted behind the objective assembly; stand O has no light source, and is intended for use with external illuminators. A transmitted light illuminator (shown to the left of the stand in *Figure 3.22*) can be supplied as an accessory.

Wild M5A (Wild Heebrugg/E. Leitz (Instruments) Ltd)

This is a stereo microscope with a four-position turret lens giving fixed basic magnifications of 6×, 12×, 25× and 50× with 10× widefield eyepieces. Working distance is 91 mm. Field of view at 6× is 35 mm. A basic microscope can be supplied with a plain stage plate and an adjustable incident light source with regulating transformer. ($2560).

Accessories include a transmitted light stand ($270), a light-field/dark-field stand ($1378) and a co-axial (through the objective) illuminator ($865). Also available are supplementary lenses of 0.3, 0.5, 1.5 and 2×, together with 15× and 20× eyepieces.

A version of this microscope, the M5APO, has been designed for high contrast and accurate colour imaging. It is available in the same basic configuration as the M5A. ($3300), and with the same range of accessories.

Wild M7A (Wild Heebrugg/E. Leitz (Instruments) Ltd)

This is a stereo zoom microscope (5:1 ratio). Basic magnification range is 6× to 31× with 10× widefield eyepieces. Working distance is 91 mm. Field of view at 6× is 35 mm. A basic microscope can be supplied with a plain stage and adjustable incident light source with regulating transformer. ($2870). Accessories are as for the M5A.

Stereomicroscope MST127 (Labimex/Micro Instruments (Oxford) Ltd) (*Figure 3.23*)

This is a low-cost stereo microscope made by PZO of Poland. It has basic magnifications of 12×, 24×, 36× and 60× selected from a range of inter-changeable lenses provided with the unit ($413). Working distance with the 1× objective is 136 mm. Field of view at 12× is 16 mm. 17× eyepieces are provided, together with a wire stand and illuminating mirror which enables the microscope to be tilted through 20 degrees for ease of viewing.

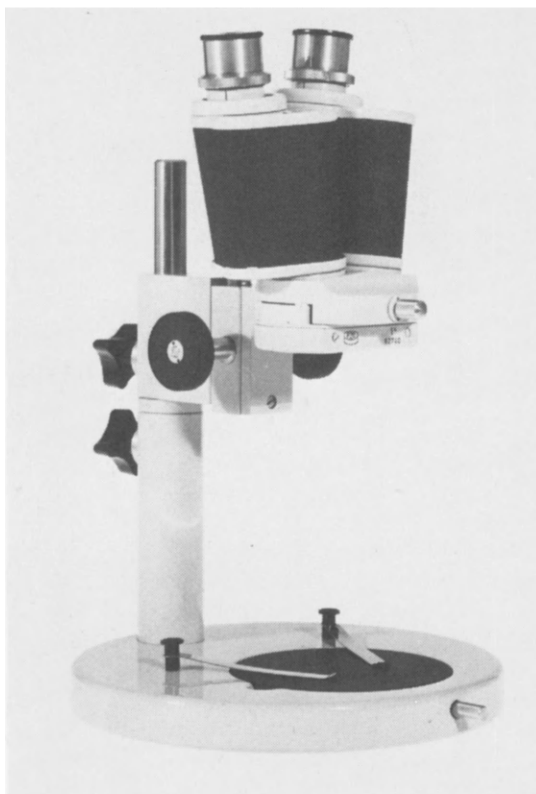


Figure 3.23
The MST127 stereo microscope (Labimex/Micro Instruments (Oxford) Ltd)

Stereomicroscope MST131 (Labimex/Micro Instruments (Oxford) Ltd)

This is a stereo microscope with a 5-position turret lens providing basic magnifications of 4×, 6.3×, 10×, 16× and 25×, with 6.3× eyepieces. Incident light and transmitted light illumination sources are provided. Working distance is 100 mm. Field of view at 10× is 17.5 mm. ($916). A supplementary lens of 1.6× is available.

Prior S2000 range (Prior Scientific Instruments Ltd)((*Figure 3.24*)

The lowest price instruments in the S2000 range are the S2021 and S2023 stereo models with 10× and 20× basic magnifications respectively and simple bench stands without illuminators. ($240). Other models incorporate 2-position and 3-position supplementary lens changers giving fixed magnifications of from 5× to 40×. These versions use combinations of incident light and transmitted light stands. A trinocular photographic head is available for all models ($50 extra). Model S2014T (shown in *Figure 3.24*) is a trinocular version with a basic 10× magnification and a

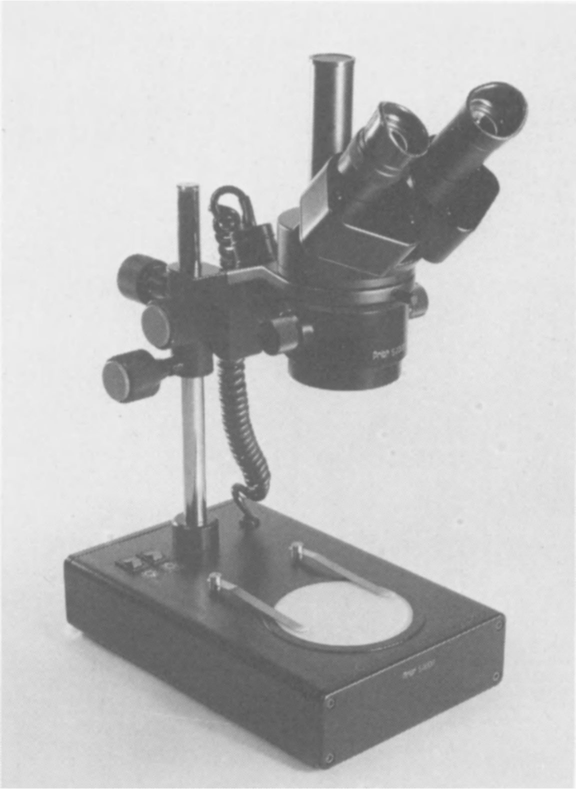


Figure 3.24
The Prior S2014T stereo microscope (Prior Scientific Instruments Ltd.)

supplementary lens changer giving magnifications of 5×, 10× and 20×. A combined incident and transmitted light stand is fitted as standard. ($444).

Accessories include 20× eyepieces, a magnification changer unit (for the basic models) containing 0.5×, 1× and 2× lenses, and a supplementary 2× lens.

Diamond grading microscope DXIIFEDV (Okuda)

As this microscope is fitted with a colour grading eyepiece attachment, it is described under 'Colour measuring instruments' in Chapter 4.

Gem tester DX (Nihon Hoseki-Kizai Co. Ltd)

This is a fixed magnification (20×) jeweller's stereo microscope with 10× eyepieces and built-in incident and transmitted light sources. The transmitted light source is fitted with an iris control. The incident light source contains a fluorescent lamp for diamond grading purposes. A stone holder is fitted as standard and 20× eyepieces are available. ($820).

Stereozoom 7 series (Bausch and Lomb)

Using the 'Power Pod' concept, this series employs a sealed stereo zoom objective assembly with a magnification ratio of 1× to 7×. ($1300). The eyepieces, which are inclined at 45 degrees to the vertical, are widefield versions available as 10×, 15× and 20×. ($140 each pair). Supplementary lenses of 0.25×, 0.3×, 0.5×, 1.5× and 2× can also be supplied.

The working distance using the 10× eyepieces is 77 mm, and the field of view at 10× is 20 mm. A wide range of stands, illuminators and accessories is available. 'B'-type stand with sub-stage mirror for light-field or dark-field illumination with separate optional light source, ($310).

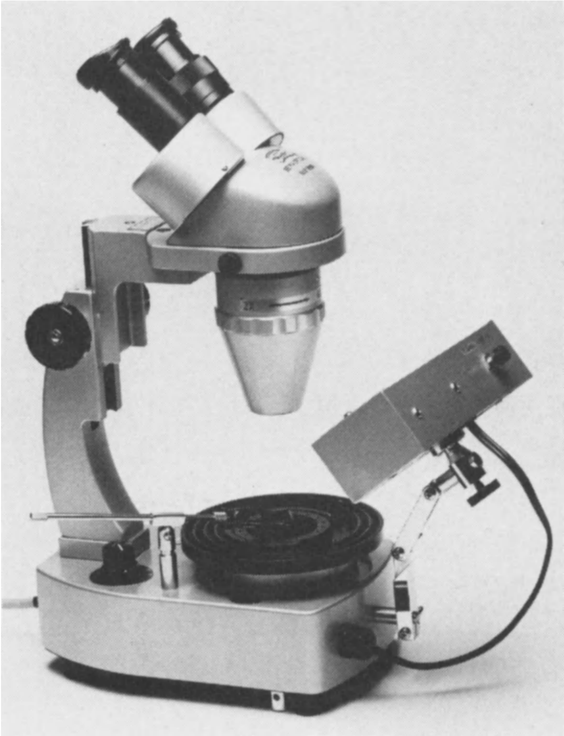
SJM-2 Correct microscope (Gemmological Instruments Ltd)

(Figure 3.25)

The SJM-2 is a stereo model with a 2-position turret objective giving overall magnifications of 20× and 40× with 10× widefield eyepieces. The microscope is fitted with a fluorescent daylight-type incident illuminator (suitable for diamond colour grading) together with sub-stage light-field and dark-field illumination. The stage is also fitted with an iris control and a left-hand or right-hand mount for a stone holder.

The optic head includes both dioptic and interpupillary adjustments, and can be rotated through 360 degrees relative to the stage. Friction-loading on the focus adjustment can be varied by contra-rotation of the

Figure 3.25
The SJM-2 Correct stereo microscope (Gemmological Instruments Ltd.)



two focus controls. A pivoting foot on the base of the unit enables it to be tilted for comfortable viewing. The SJM-2 is a low-cost microscope suitable for both student and professional use. ($1100).

Optional accessories include 5× eyepieces (for diamond clarity grading).

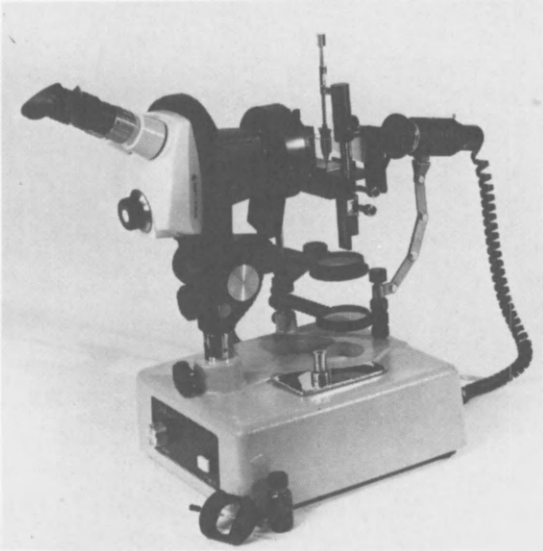
Bi-directional stereozoom microscopes (Gem Lab) (*Figure 3.26*)

The Gem Lab range comprises three microscopes whose optical heads can either be mounted horizontally, for immersion work, or vertically. All models include a transmitted light illuminator with polarisers/konoscope attachment, a neon-ring dark-field illuminator, and an immersion cell mounted on an X-Y stage.

System 7 uses a Bausch and Lomb Stereozoom 7 optical head with a basic magnification range of 10–70× using 10× widefield eyepieces. Working distance is 76 mm. Field of view is 20 mm at 10×. ($2995).

System 5 uses a Bausch and Lomb Stereozoom 5 optical head with a basic magnification of 8–40× using 10× widefield eyepieces. Working distance is 100 mm. Field of view is 24.9 mm at 8×. ($2690).

Figure 3.26
The Bi-directional stereo zoom microscope head can be mounted either horizontally (as shown) or vertically. (Gem Lab)



System 4 uses a Bausch and Lomb Stereozoom 4 optical head with a basic magnification of 7–30× using 10× widefield eyepieces. Working distance is 100mm. Field of view is 28mm at 7×. ($2630).

Accessories for all models include 15× and 20× widefield eyepieces and 2× supplementary lenses.

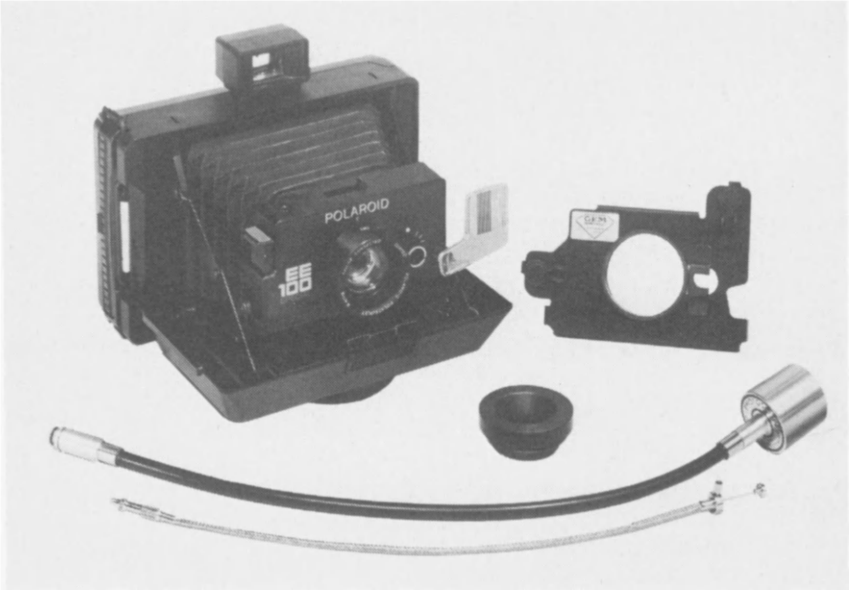
MICROPHOTOGRAPHY

In gemmology, microphotography provides a means of establishing a photographic data bank which can play an important part in helping to identify gemstones. It can be used, for example, to locate the origin of stones and to decide whether a gem is natural or synthetic[1]. The internal characteristics of a specific gemstone can also be photographed to form a 'fingerprint' for later identification.

Techniques of photographing the interior or exterior of a gemstone through the microscope lens are not entirely involved with the mechanics of attaching the camera to the microscope. Of equal importance is the cleaning of lenses and stones, the elimination of vibrations, especially where long exposures and high magnifications are used, experimentation with incident, light-field and dark-field illumination, and the use of polarising filters[2].

Although the use of immersion techniques to reduce surface reflections when photographing internal features in a gemstone is theoretically sound, thermal currents caused by heat from the light source, combined with dust particles within the liquid, may degrade the picture image. If an immersion liquid is used, it should first be passed through a membrain type filter to remove any dust particles.

Figure 3.27
The Photoscope camera is attached to one eyepiece of a stereo microscope and the exposure control fibre optic coupler to the other (Gem Instruments Corporation)



For photographic purposes, most manufacturers either supply a trinocular model which has a separate port for the attachment of a camera (thereby leaving both eyepieces available for normal viewing), or provide a camera attachment which is inserted in place of one of the stereo eyepieces. With the Gem Instruments Corporation Photoscope (*Figure 3.27*), the Polaroid camera is attached to one eyepiece with an adaptor, and a fibre-optics coupler is attached to the second eyepiece to give automatic exposure control.

When using a single-lens reflex (SLR) 35 mm camera, with built-in photoelectric light indicator, exposure settings are arrived at relatively easily. Even here, some allowance must be made for the averaging characteristics of most light meters. To compensate for this it may be necessary to increase exposure times for dark subjects in areas of high illumination, and decrease it for lighter subjects surrounded by mainly dark areas.

At high magnifications, the depth of focus of the microscope becomes very limited, and problems arise when trying to photograph a longitudinal or curving feature. If the microscope uses a twin-objective stereo system, the depth of focus can be increased by placing over the appropriate objective lens an opaque mask having a 1 to 2 mm circular hole in its centre (i.e. stopping down the lens). As this greatly reduces the amount of light reaching the camera, exposure times have to be increased accordingly.

Provision for improving the depth of focus by closing down a built-in iris diaphragm is included in one of the special-purpose Wild microscopes (Model M450). For photographic purposes, the objective in another Wild microscope (Model M75) is swung out to lie centrally in the optical axis of the left-hand beam path, making the system monocular in order to fully exploit the well-corrected central part of the objective lens.

Inspection lamps

A variety of inspection lamps or light sources is available. Some of these are designed specifically for use with a microscope or spectroscope, or for diamond grading, and some are intended for more general work with hand or head loupe.

Labsource fibre optic illuminator QH-150 (PBL/Auriema Ltd.)
(*Figure 3.28*)

This unit consists of a control box containing a 150 W quartz halogen lamp with an integral reflector which is used to focus the light into the fibreglass light guide. Heat is removed by a fan. A variety of lengths of single and double-outlet bifurcated flexible light guides are available, which plug into an adaptor ring on the control box.

This unit is particularly suitable as a light source for a spectroscope or a microscope. It operates from mains supplies of 105–125 V 60 Hz, and a 220 V, 50 Hz version is available. ($480, 1/4 in dia. light guide $336).

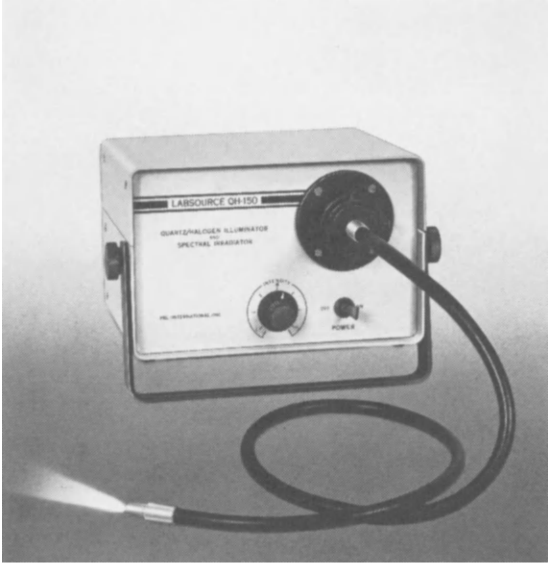


Figure 3.28
The Labsource fibre optic illuminator (PBL/Auriema Ltd)

Figure 3.29
Allen Type M7 bench magnifier
(P. W. Allen & Co.)

Rayner high intensity lamp (Gemmological Instruments Ltd)

This consists of a pre-focused 12 V, 24 W lamp in a lamp housing. This is mounted via a flexible arm from a base, which houses a 110–130 V, 60 Hz or 210–240 V, 50 Hz mains transformer. ($218).

A filter holder can be supplied for fitting to the lamp housing. This holder will take 2 × 2 in filters. ($31).

M7 illuminated bench magnifier (P. W. Allen & Co) (*Figure 3.29*)

Intended for bench work where frequent adjustment is necessary, the M7 unit uses a 5-in dia. lens having a magnification of 2×. A circular 22 W fluorescent lamp provides shadowless illumination. ($163).

The lamp is available for 220–240 V, 50 Hz or 110–115 V, 60 Hz supplies.

M5 illuminated bench magnifier (P. W. Allen & Co)(*Figure 3.30*)

This unit uses the M7 lens and lamp assembly mounted via an adjustable stirrup to a low profile base unit. ($176).

Figure 3.30
Illuminated bench magnifier, Model M5 (P. W. Allen & Co)

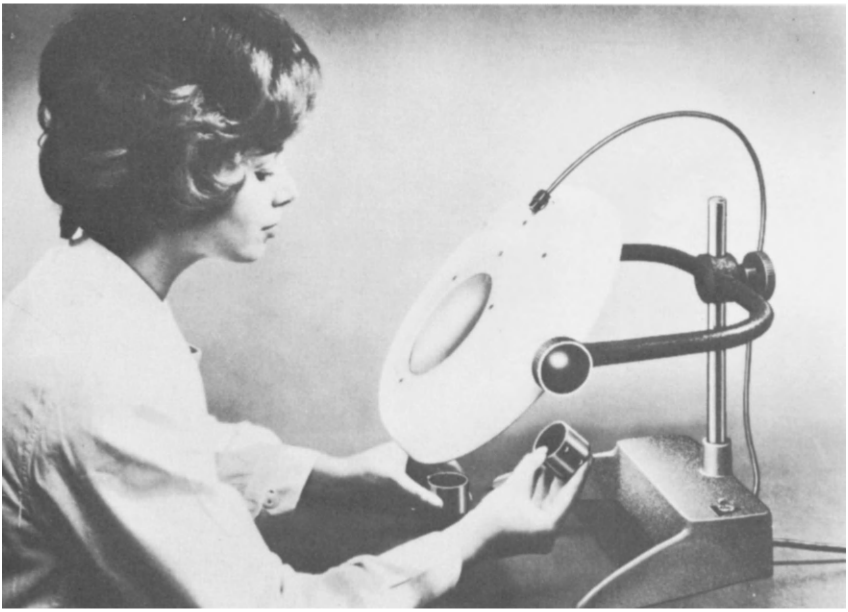
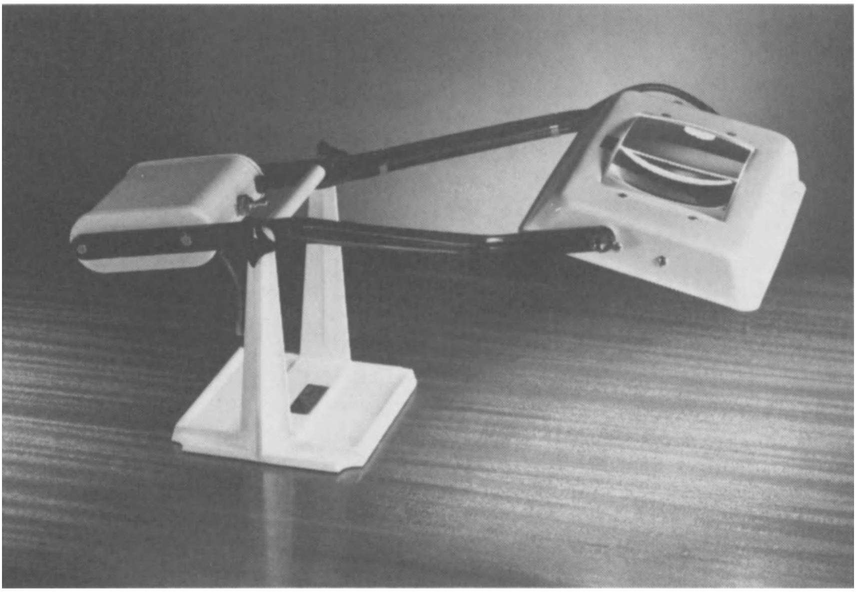


Figure 3.31
The STD counterbalanced illuminated magnifier (IVA Engineering Co Ltd)



STD illuminated bench magnifier (IVA Engineering Co Ltd)(*Figure 3.31*)

Using a rectangular 152 × 88 mm lens with a magnification of 2×, the STD unit is mounted on a swivel arm which is counterbalanced by the light-control box. The twin 6 W fluorescent lamps are mounted in the lens housing. The lens focus gives a working distance of 250 mm, and a field of view of 100 × 70 mm. ($180).

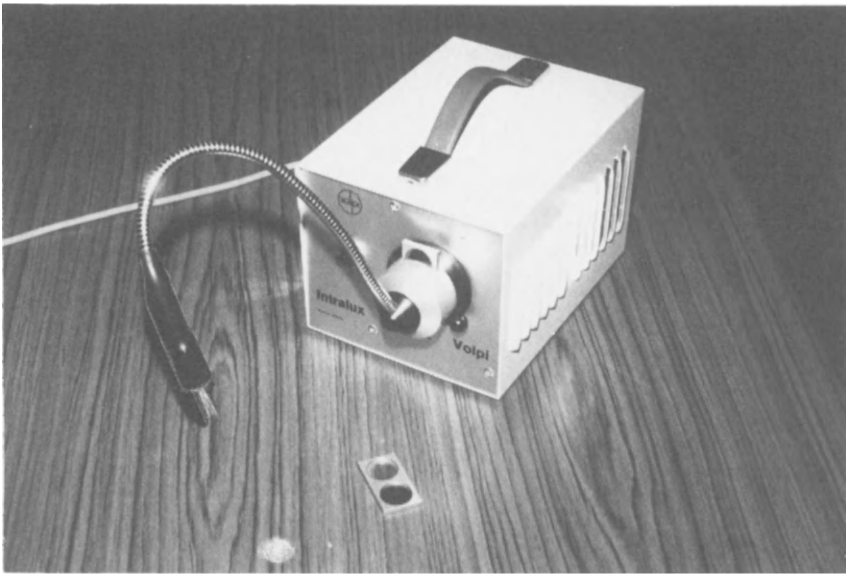
A general purpose version, Model GP, is fitted with a 2× lens which gives a working distance of 400 mm, and a field of view of 300 × 230 mm. ($164). A bifocal version, Model B-F, has a compound lens built into the top centre edge of the main lens to provide dual magnifications of 2× and 4× (working distances of 240 mm and 85 mm; fields of view of 100 × 70 mm and 40 × 20 mm). ($250).

All models can be supplied in 110/115 V and 220/240 V versions (the 110/115 versions cost $24 extra).

Intralux 150H (Volpi/Huddlestone Gemmology Consultants Ltd/Capital UE Ltd) (*figure 3.32*)

This is a cold light source which can accept a range of glassfibre light guides and attachments. The unit employs a 15 V, 150 W halogen lamp, with a heat filter. Cooling for the lamp is by means of a low-noise fan. a holder is fitted for colour filters (blue, green, yellow and red) which can

Figure 3.32
The Intralux 150H (Volpi/Huddlestone Gemmology Consultants Ltd/Capital UE Ltd)



also be provided. ($360). Model 250HL includes an optical system for even illumination. ($550).

Suitable light guides for gemmological work are as follows:
Semi-rigid swan neck light guide suitable for incident illumination and spectroscope work. ($80). Optional focusing lens ($44).
Mixed acrylic fibre light guide in PVC jacket. ($116).

References

1 Gübelin, E., Internal World of Gemstones.
2. Koivula, J. I. 'Photographing Inclusions', Gems and Gemmology (Fall 1981).

4

Colour (including spectral absorption and pleochroism)

Selective Absorption. Allochromatic and Idiochromatic minerals. Dichroscopes. Colour filters. Colour grading. Colour measuring instruments.

In the two previous chapters, we have discussed the preliminaries of cleaning gemstones and of assembling the tools and equipment necessary for the handling and inspection of them. Now we are ready for the first part of the investigation into their identities.

This initial inspection will be a mainly qualitative assessment, and will include characteristics such as colour, surface and internal features, and, in the case of uncut stones, shape. We have already briefly mentioned the diagnostic value of surface features, inclusions and shape in chapter one, and, as this book is mainly concerned with the use of instruments, have already referred the student gemmologist to the appropriate gemmological books which deal with these subjects in more detail. This chapter will therefore be confined to the exploration of colour in gemstones, and will describe the instruments which have been developed to aid the analysis of this quality.

SELECTIVE ABSORPTION. ALLOCHROMATIC AND IDIOCHROMATIC MINERALS

The colour of a transparent gemstone is caused by the selective absorption of various wavelengths in the white light passing through it[1]. In opaque stones, this selective absorption takes place in the light as it is reflected back from the surface of the stone. The absorption is either caused by chemical impurities in the gemstone which affect the crystal lattice (e.g. chromium oxide impurity in ruby), and which is then described as being 'allochromatic', or is caused by the stone's own chemical composition (e.g. the manganese in the composition of rhodonite), when it is called 'idochromatic' (see 'Transition Elements' under 'Absorption and emission spectra' in Chapter 1).

It is possible for two distinctly separate minerals, which selectively absorb different groups of wavelengths, to have the same colour. This is because the overall effect of the spectral response for each gemstone is the same. The best way to distinguish between such minerals on a colour basis is to analyse their individual absorption bands by means of a spectroscope.

Because the spectroscope effectively analyses the chemistry of the stone in terms of selective absorption, some of its results are concerned with diagnostic features which are not necessarily associated with colour. For this reason, this most important gemmological instrument is dealt with separately in a later chapter.

DICHROSCOPES

If a coloured stone is doubly refracting, and possesses the optical quality of pleochroism, then the two rays passing through it will experience different selective absorptions, and will emerge differing in shade (or saturation) and sometimes in colour (or hue). As pleochroism in a gemstone can often be a useful identifying feature, and as it is not often easy to see with the unaided eye, an instrument called a Dichroscope was developed.

The dichroscope (*Figure 4.1*) consists of a rhomb of calcite (iceland spar) which is housed in a metal tube having an eyepiece and lens at one end, and a square aperture at the other. A glass prism is cemented to each end of the calcite rhomb to allow the light to enter and leave the rhomb in a straight line. Light passing through the gem under test enters the aperture, and is split into two rays by the strong double refraction of the calcite. If the gem is dichroic, and is viewed in a direction other than that of the optic axis, the two rays, which appear in the eyepiece as two side-by-side images of the aperture, will differ in shade or colour. If, however, the twin images are exactly the same shade and colour, then the stone has no pleochroism, and is most probably singly refractive.

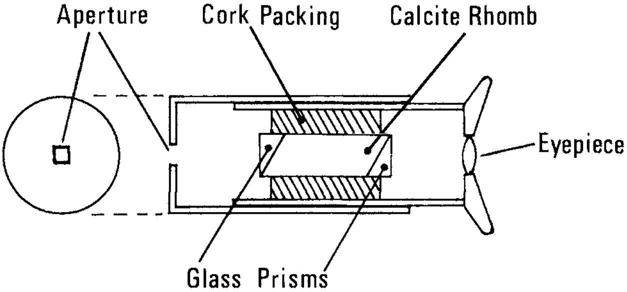


Figure 4.1
Diagram showing construction of the prism-type dichroscope

As little dichroism will be seen if the optical axis of the stone under test is in line with the rhomb, the stone must be rotated until the maximum shade or colour difference is obtained.

Dichroism in a gemstone can also be detected by the use of a piece of Polaroid plate or sheet. If the gem is viewed through such a filter, and the filter is rotated, this will block first one, and then the other, of the polarised rays emerging from the stone, and will permit consecutive viewing of the two individual shades or colours. Dichroscopes using polarising filters have the filter split into two sections, with one rotated through 90 degrees, to avoid the need for rotation.

Three commercial dichroscopes are described in the following section:

COMPARATIVE VALUE GUIDE
The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

Rayner dichroscope (Gemmological Instruments Ltd)(*Figure 4.2*)

This is a compact instrument employing a calcite rhomb and measuring 50 × 14 mm. ($50). It can be used either with a clip-mounting table stand, which includes a rotary platform for the stone under test ($27), or with a clip-on attachment which is fitted with a rotatable stone mount ($16).

Figure 4.2
The Rayner dichroscope showing clip-on stone holder (Gemmological Instruments Ltd)

Gem dichroscope (Gem Instruments Corp)

Overall, this calcite rhomb dichroscope is slightly smaller than the Rayner (38 × 16 mm). However, as its barrel diameter is similar to that of the Rayner, it can be used with the same attachments. ($15).

PD-240 dichroscope (Hanneman Lapidary Specialties. ($15).

Hand dichroscope (Hans-Günter Schneider) ($45)

These dichroscopes, unlike the Rayner or the Gem Instrument models, use polarising filters to separate the two plane polarised rays from a coloured doubly-refracting gem, and thus reveal any differences in shade or colour in these rays. The limitation with this type of dichroscope compared with the calcite rhomb version is that two adjacent sections of the stone under test are viewed through the two sections of the filter. With the calcite rhomb version, light from a single section of the stone is split into two side-by-side images, making it more practical to check smaller stones.

COLOUR FILTERS

Chelsea colour filter (Gemmological Instruments Ltd)

Another colour aid, developed to distinguish between genuine emeralds and their paste and doublet simulants, is the Chelsea colour filter (*Figure 4.3*). This filter was the outcome of research work carried out in the Gem Testing Laboratory of the London Chamber of Commerce and at the Chelsea College of Science and Technology. ($14).

The filter is made in the form of a hand loupe, And consists of a combination of two gelatine filters designed to transmit only deep red and yellow-green light. This particular combination was chosen to match the unusual spectral response of emerald, which permits the transmission of light in the deep red, but absorbs it in the yellow-green. In use, the filter should be held close to the eye and the stone under test positioned under a strong light source.

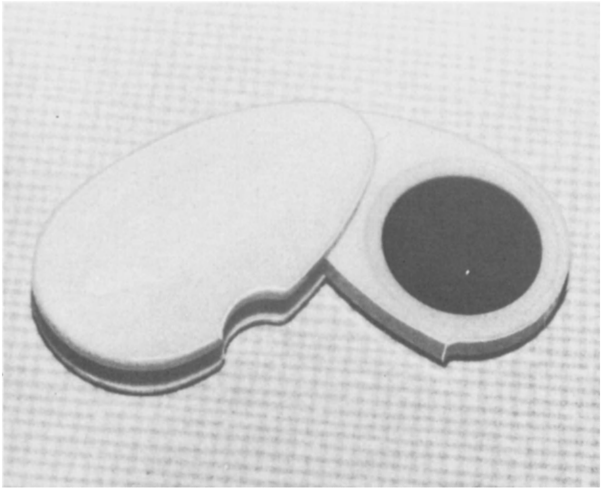


Figure 4.3
The Chelsea colour filter combines two colour filters to match the spectral response of emerald (Gemmological Instruments Ltd)

When several green stones are strongly illuminated and are viewed through this filter, the genuine emeralds will appear distinctly red or pinkish in colour (depending on the depth of colour of the emerald), while green faceted glass, doublets and most soudé emeralds will appear green. There are, unfortunately, several exceptions to the filter's ability to identify genuine emeralds and to reveal simulants. Some emeralds, in particular those from South Africa, may not appear red or pink through the filter (fortunately these cases are relatively rare). In addition, synthetic emeralds react in the same way as natural emeralds, but the red colour usually appears more brilliant. Demantoid garnet and green zircon also have a pinkish appearance through the filter.

On the credit side, however, the filter can be used to identify both natural and synthetic ruby, as these appear as a characteristic brilliant red, (due to the presence of chromium oxide). Synthetic blue spinels can also be tested, as these appear yellowish-orange or pink, which serves to distinguish them from aquamarine or sapphire, which appear green or greyish green. Unlike naturally-coloured green jadeite, dyed jadeites tend to appear red or pinkish under the filter.

As no naturally occurring transparent gem minerals contain cobalt, and as cobalt coloured materials appear pink or red through the filter (e.g. synthetic blue spinel and blue cobalt glass) any transparent blue gemstone which shows these colours through the filter should be suspect.

Sterek A filter (D. Walters)

This is a two-colour filter (mounted in a plastic 35 mm slide holder) which was introduced in the UK market in 1980. ($6). Unlike the Chelsea filter, the Sterek A was developed as the result of a series of experiments on the fluorescence of rubies under crossed filters (see Chapter 9). The new filter transmits colour in the red end of the spectrum from around 670 nm upwards (as does the Chelsea filter), but instead of a relatively narrow 'window' in the yellow-green around 570 nm, it passes a broader band of colour in the blue-green, centred on 520 nm.

The overall response of the filter favours the main transmission bands in sapphire and aquamarine, the latter gem showing an intense blue/green through the filter, in contrast to the pink/red appearance of the pale blue synthetic spinel simulant. The filter's higher transmission in the red also causes chromium coloured stones, such as natural and synthetic rubies and alexandrites, to appear a brighter red compared with their response through the Chelsea filter. Despite the difference in transmission response between the two filters, it is still possible with the Sterek A to distinguish most emeralds from their simulants.

Emerald filter (Nihon Hoseki-Kizai Co. Ltd)

This is similar in appearance to the Chelsea colour filter (*Figure* 4.3) and is said to be particularly suitable for the detection of dyed jades. ($10).

GemMaster ruby discriminator (R. Lary Kuehn Inc.)

This is a green filter (mounted in a 2 × 2-inch card holder) which discriminates between chrome-rich and other gemstones. When a stone is viewed through the filter under a strong white light, its colour appearance through the filter ranges from bright blue for a ruby, through dark grey-blue for a red spinel and dark purple for red glass, to dark brown for pyrope. As with the emerald filters, the ruby discriminator cannot distinguish between natural and synthetic stones. ($6).

COLOUR GRADING

While the grading of polished gem quality diamonds by colour is a well-established art which is rapidly becoming a science, the classification of coloured gemstones into meaningful divisions of hue, saturation, colour purity and brightness is still in its infancy.[2]. The reason for this is the difficulty in establishing standards to cover the wide range of variables met with in coloured stones. The majority of diamond and coloured stone grading laboratories employ subjective techniques in which the gemstone is compared for colour with a set of master stones. A few laboratories however, are pioneering the use of instruments in the assessment of colour. A detailed appraisal of the various national and international diamond grading standards,such as that employed by CIBJO[3], is given in Chapter 14.

COLOUR MEASURING INSTRUMENTS

Although eight of the instruments described in this section are designed for diamond grading, they have been included in this chapter (rather than in chapter 12, which deals with diamond grading), as they are basically colour measuring devices.

Colour measuring instruments[4, 5] can be divided into four main types:

1. Electronic photometers, which measure the luminous intensity of light, and which can be used with suitable filters to analyse the colour of that light (i.e. filter-photometers).
2. Tristimulus colorimeters, which analyse the colour of a specimen via red, green and blue/violet filters. These filters are arranged to match the visual response of the human eye, and thus enable CIE[6] tristimulus values to be measured without the computations necessary with a spectrophotometer.
3. Visual colorimeters, which use the eye to match combinations of standard colours (usually in the form of colour slides) with the colour of the sample being measured.
4. Spectrophotometers, which employ a tuneable monochromator to explore the absorption or reflectance characteristics of the specimen at a series of wavelengths across the visible spectrum (and often the near

infra-red and U-V). To convert these readings into CIE tristimulus values they must be individually multiplied by red, green and blue/violet distribution coefficients (as determined by the CIE for a standard observer) at each wavelength. Each of the three sets of colour-corrected readings are then added to produce the X, Y and Z tristimulus values. The colour angle, colour saturation and brightness of the sample can then be calculated, and the first two of these parameters plotted as x and y co-ordinates on a CIE colour chart, where:

$$x = \frac{X}{X + Y + Z} \qquad y = \frac{Y}{X + Y + Z}$$

Note: By adjusting the distribution coefficients, tristimulus value Y is used as a 'vertical' co-ordinate representing brightness in the CIE three-dimensional colour solid.

Automatic absorption/reflectance curve plotting and the calculation and printout of CIE colour co-ordinates are often a built-in feature of a spectrophotometer.

While the tristimulus colorimeter and the spectrophotometer are capable of measuring any colour in the visible spectrum, they are relatively complicated devices, and for this reason diamond colour grading instruments have usually been of the photometer type. As the colour to be measured is limited to a small range in the yellow, the photometer version can be further simplified by reducing the sampling wavelengths or colours to two.

Diamond-Photometer (Eickhorst) (*Figure 4.4*)

This instrument is of the filter-photometer type using colour-filtered yellow and blue light to measure the absorption of the diamond at these wavelengths, and is therefore only suitable for the grading of those diamonds in the Cape series, white to yellow. ($4545).

As can be seen in the diagram in *Figure 4.5*, yellow and blue light is directed, in turn, into the table facet of the diamond by means of a glass fibre light guide. Use is made of the optics of the brilliant cut stone to achieve total internal reflection of the sampling light, which is then collected as it emerges from the table facet by a second concentric light guide. The output of this second light guide is fed to a photo detector which is connected to a meter to indicate the intensity of the yellow and blue light.

These two intensities are called T1 and T2, and the ratio of these two figures is called the transmission quotient (by taking the ratio of T1 and T2, the effects of path length differences in diamonds of different size are cancelled out). The transmission quotient number is then converted to the appropriate diamond colour grade by means of a graph on the front of the instrument. Before each measurement is made, a white calibration plate is

Figure 4.4
The Diamond-Photometer uses the ratio of monochromatic yellow and blue light to measure the colour grade of Cape series diamonds (Eickhorst)

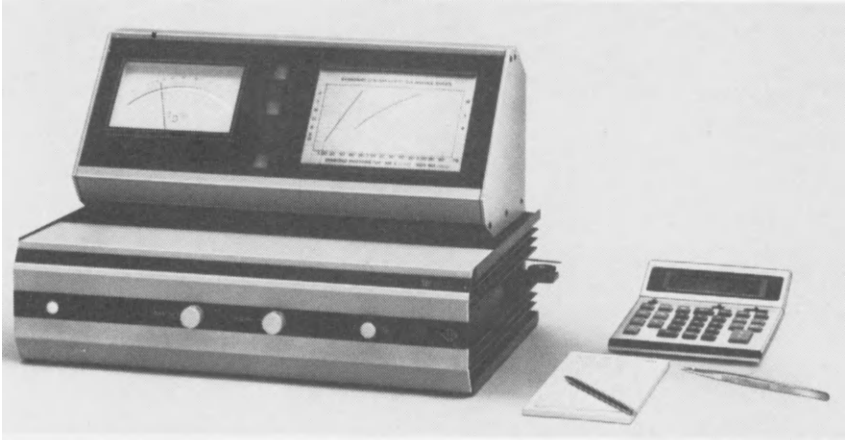
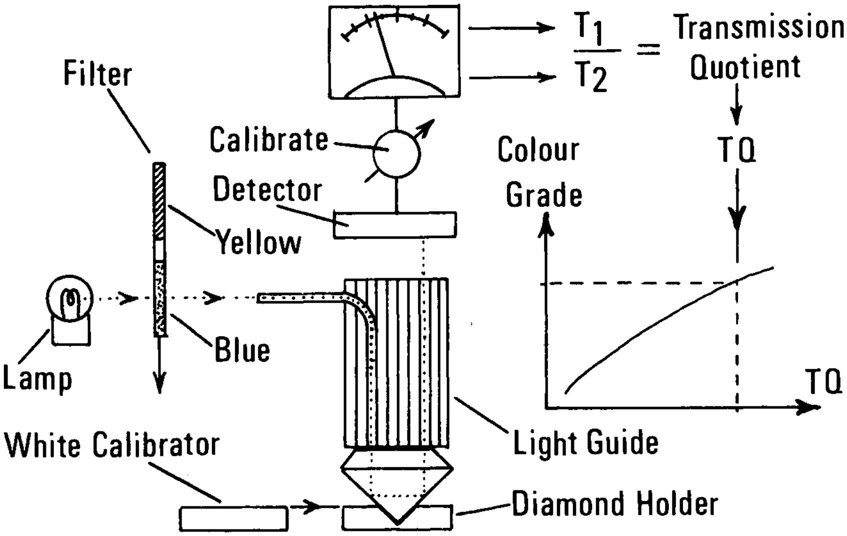


Figure 4.5
Diagramatic representation of the Eickhorst photometer. T1 is the intensity of the transmitted blue light, and T2 the intensity of the transmitted yellow light



placed under the fibre optic head (in place of the diamond), and the calibration control is adjusted for a 100% transmission reading on the meter.

As previously explained, the photometer is only intended for the measurement of Cape series diamonds, and those having a brown or green tint will give incorrect readings. Before being tested, diamonds should also be checked for fluorescence, as blue fluorescing stones will also give incorrect readings. The reason for this is that the U-V component in daylight, or in diamond grading lamps, causes the diamonds to appear whiter (because of the blue fluorescence) than the colour indicated by the instrument, whose yellow and blue sampling light does not excite fluorescence.

Shipley electronic colour grader

This diamond photometer, now long obsolete, is of the two-wavelength (yellow, blue) photometer type. It was designed by Mr. R. Shipley (of the Gemological Institute of America and the American Gem Society), but was only made available to members of the American Gem Society.

Diamond colour meter (Tatsumi/Nihon Hoseki-Kizai Co. Ltd)

This is a filter-photometer type instrument using a white light source (with no U-V component) derived from a xenon lamp. The yellowness of a Cape series diamond over the GIA grades D to M is measured by means of two colour filters which enable the unit to compute the grade from the ratio of light transmission in the yellow and blue. The sampling light is fed into the table facet of the diamond under test by means of a glass-fibre light guide. A second light guide collects the totally internally reflected light and feeds it to the photodiode. ($1560).

Because of the method of light sampling, mounted as well as unmounted diamonds can be tested. As is normal with this method of colour measurement (see the Eickhorst Diamond Photometer) green and brown diamonds do not produce accurate results. For the same reason, as no fluorescence is stimulated in a blue or yellow fluorescing diamond, this will also result in colour grade differences with these stones when compared with standard subjective grading or full-range spectrophotometer analysis.

Lovibond-Nelson microcolorimeter

A colour-comparator microscope, which can be used to establish classifications for coloured gemstones, has been developed by McCrone Research Associates Ltd. in association with Tintometer. ($6000)

This instrument enables the sample to be viewed and compared simultaneously with a set of eighty calibrated colour filters. These are mounted permanently in moveable slides and can be inserted into the field of view to give combinations of hue and colour saturation. When the nearest colour match has been achieved with the filters, their reference numbers can be converted to CIE[6] co-ordinates for classification purposes.

As this instrument uses the eye to compare the colour of a sample with that of calibrated colour filters, it can be classified as a visual colorimeter.

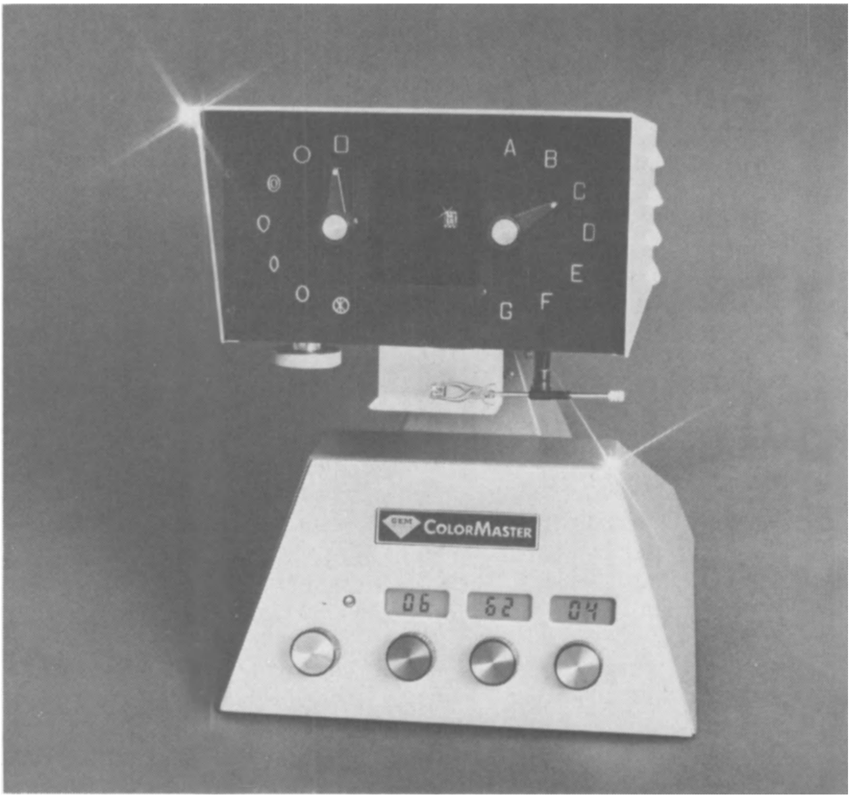
ColorMaster (Gemological Instruments Corporation)(*Figure 4.6*)

The ColorMaster is a visual colorimeter enabling a colour image of a gemstone to be matched to a specimen by means of three controls which vary the intensity of red, green and blue light sources. ($2950).

To produce this image, outputs of the three light sources are injected into a series of colourless synthetic spinel models which have various shapes ranging from the emerald cut and the brilliant cut to the cabochon. A shape control is provided to enable a spinel to be selected having the appropriate cut, and a zoom-type control allows the size of the resulting image to be matched to that of the sample. Additional controls give adjustment of the overall brightness and colour modification of the image.

The stone holder for the gem being matched is mounted in front of a white background just below the image viewing area. To allow for colour-change gems, the illumination for the stone can be changed from daylight-type to filament light.

Figure 4.6
The ColorMaster is a visual colorimeter in which the colour of a gemstone is matched by adjusting the intensities of red, green and blue light sources



The intensity of each of the three coloured light sources is indicated above the appropriate control by means of digital LCD displays, which show the light level on a scale of 0–100. When the synthesised colour of the image has been matched as closely as possible to the gemstone, its red, green and blue colour components are read from the LCD display panels. The ColorMaster notation prefixes these values with a code indicating the shape and coloration modifier (e.g. for an oval brilliant-cut deep blue sapphire, OC 00/18/82).

The ColorMaster was originally designed as a means of communicating the colour appearance of gemstones for the purposes of matching and selling. For colour grading purposes, however, the accuracy of the instrument's results depends largely on the colour sensitivity of the user, and on his or her skill in the blending of the primary colours (the latter being a matter of practice). Limitations in some of the paler and deeply saturated shades may also limit the instrument's suitability for the colour grading of gemstones.

GemMaster Color System (R. Lary Kuehn Inc.)

This consists of a set of twenty-six numbered colour transparencies, four neutral density filters (ranging from 10% to 80% absorption) and a 110 V mains-operated light box containing a 4 W fluorescent lamp. ($130). The colour slides span the spectrum from red to violet, while the neutral density filters are used to increase their effective colour saturation, the combination of slides and light box constituting a visual colorimeter.

When using the slides to colour-match a gemstone, the stone is placed on the light box with its table facet downwards. The colour slide nearest to the body colour of the gemstone is placed alongside it on the light box, and additional slides and neutral density filters are stacked on top of the first slide until the nearest match is achieved in hue and colour saturation. The colour specification of the gemstone is then derived by listing the code numbers of the slides in the stack (e.g. a brownish ruby is No. 1, 26, 65%).

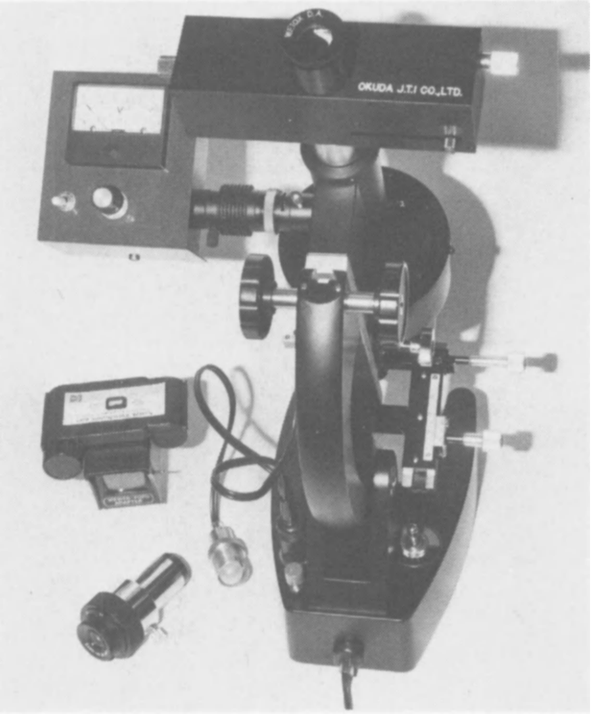
Diamond grading microscope DXIIFEDV (Okuda)(*Figure 4.7*)

For the purpose of colour grading, this instrument can be classified as a visual colorimeter. It is fitted with a colour comparator eyepiece in which a diamond's body colour can be matched with a calibrated yellow filter glass. ($2000).

The range of the eyepiece covers the GIA grades D to K. In addition, a slide control enables either a proportion graticule, a colour grading 'window', or a clarity measuring graticule to be introduced into the field of view. The Okuda diamond grading microscope also has an electronic photometer unit which can be used to assess the brilliance and cut of a diamond (in terms of its total internal reflection of light).

A circular daylight grading lamp is independently adjustable in height on the focus mount, and a green co-axial illuminator can be brought into

Figure 4.7
Diamond grading microscope DXIIFEDV is fitted with a colour comparator eyepiece (Okuda)



use to enable SPD codes to be made visible on the table facet of a diamond (see the Okuda SPD process in Chapter 14).

The basic magnification of the microscope is 20×, and accessories include a 10× to 20× zoom eyepiece, and a viewer/photo-adaptor which can be loaded with a flim cassette for direct photographic records.

One of the initial problems when using this microscope to colour grade diamonds is associated with the need to match the flat field of colour of the graduated yellow fitler glass with the three-dimensional view of the diamond's pavilion. This can usually be overcome by first practising with known graded stones.

Diamond colour checker DC-530A (Okuda/Gemini/Rubin) (*Figure 4.8*)

This is a compact filter-photometer for the measurement of diamond colour grades, and employs a single-beam white light source and a 100 mm dia. metal integrating sphere. GIA grades covered by the unit range from D to L, and can be measured with an accuracy of a third to a quarter of a grade, on diamonds from 0.2 carat upwards. ($3200).

When using the instrument, the top section of the integrating sphere is removed so that the diamond under test can be placed on the centre of the perspex plate sealing off the lower half of the sphere. The top half of the sphere is then replaced, the white light from a quartz halogen lamp (containing spectral components from 250 to 1200 nm) being injected into the diamond through its table facet. The resulting scattered light rays, modified by the body colour of the stone, are focused by the optics of the sphere onto a diffusing plate. The spectral response of the light falling on the diffusing plate is sampled by a colour detector which consists of two photodiodes fitted with blue and red filters, the light being shared between them by means of a beam splitter. The output from the detector is fed to an electronic ratio-computing circuit which drives a meter calibrated in GIA colour grades.

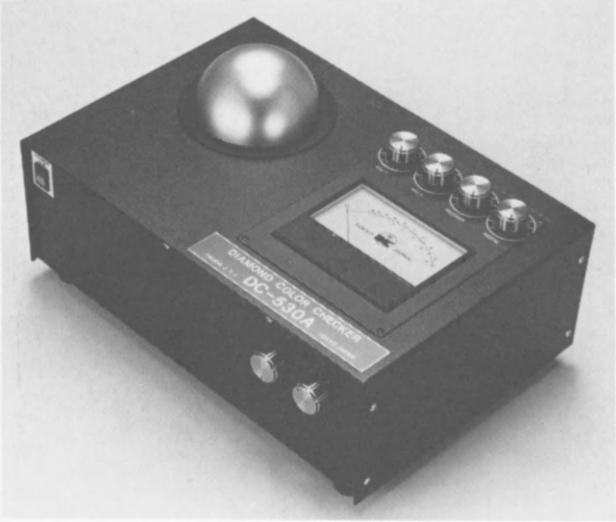


Figure 4.8
The Diamond Color Checker DC-530A uses a white light source and an integrating sphere (Okuda)

An 'Operation' switch on the front of the unit can be set for 'Manual' operation, which allows the instrument to be calibrated from a set of master stones. In the 'Automatic' position of this switch, the instrument uses internally programmed calibration settings provided by Okuda.

Two further controls allow corrections to be made for the carat size of the diamond, and (if the diamond is mounted in a ring) for the colour of the ring shank. Typically, the shank colour control (ADJ-1) is set to 70 for platinum or white gold, and the carat size control (ADJ-2) is set to 85 for 1 carat stones.

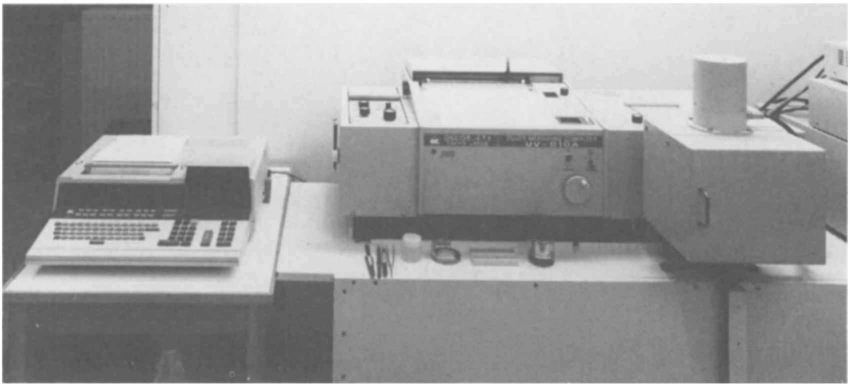
After a twenty-minute warm-up period (during which the meter zero drifts slightly) the DC-530A provides a fast readout of a diamond's colour grade, and providing that the stone is accurately placed over the centre of the light aperture, repeatable results are possible to within one third of a colour grade. As the result of the colour temperature of the light source, and the use of blue and red filters in its detector unit, the manufacturers claim that the diamond colour detector can grade stones having a brownish tinge as well as the yellow Cape series, and can provide accurate results on most fluorescing diamonds.

Diamond colour grading computer OJ-810A (Okuda)(*Figure* 4.9)

This is a full-range (350–780 nm) spectrophotometer designed specifically for the colour grading of polished diamonds. The instrument contains a 'C' type illuminant, a tuneable monochromator with a 5 nm bandwidth, an electronics control unit and a built-in chart recorder.

The associated computer unit provides a printout of the diamond's percentage reflectance at 5 nm intervals across the spectrum. In addition, the computer program prints out the calculated CIE X, Y, Z tristimulus values, the x, y colour co-ordinates, dominant wavelength, colour saturation and associated GIA colour grade. A colour grading chart is attached to the computer printout and enables the colour saturation figure to be translated into one-third of a grade GIA divisions, and also relates this to the CIBJO colour grades (see Chapter 14). An OJ-810A is installed in the Antwerp Diamond Laboratory where it has also been used to grade coloured gemstones. ($120 000).

Figure 4.9
Diamond Color Grading Computer OJ-810A is a specialised spectrophotometer with computer printout of C.I.E. colour co-ordinates and G.I.A. colour grade (Okuda)



The Gemcolour 2 (Kalnew/GAAJ)

This is a double-beam spectrophotometer designed specifically for the colour measurement of diamonds. It employs an integrating sphere having a bottom-loading sample holder with an illumination area of either 3.0 × 3.0 mm or 1.3 × 1.3 mm. The holder is of the vacuum-suction type and is rotated during measurements to obtain the mean value of the diamond's colour. The monochromator employs a blazed holographic grating which provides sufficient discrimination to enable the 415.5 nm Cape series line to be detected. With fluorescing diamonds, the blue end of the spectral scan can be limited to 400 nm to eliminate the fluorescent effect and produce a true body colour.

Once the diamond is placed in the holder and the measurement is initiated, a microcomputer in the control unit takes care of the sequencing of the 2-minute measuring cycle. The built-in thermal-type printer produces a plot of the diamond's absorption spectrum from 360 to 700 nm, and also lists the individual reflectance percentages at 5 nm intervals.

The computed tristimulus X, Y, Z values (for a standard 'C' illuminant, based on a 150 W tungsten-halogen lamp), CIE chromaticity co-ordiantes, the dominant wavelength and the excitation purity (i.e. saturation) are also printed.

Automatic wavelength correction is incorporated, giving a wavelength setting accuracy of ±0.3 nm. The wavelength repeatability is ±0.1 nm. With a diamond having as little as 1.5% colour saturation, repeatability is claimed to be within ±0.06%.

The instrument is designed for 100, 115, 220 and 240 V, 50/60 Hz mains operation. ($19 000).

Diamond spectrophotometer (DGL)

This is not a commercially available unit, but the system is described here briefly for the sake of completeness. The technique used in the DGL system for colour grading Cape series diamonds was devised by R. V. Huddlestone[7], and is unique in that it was the first spectrophotometric method ever used in a diamond grading laboratory. It is also unique in that it does not use a full spectral scan.

In the DGL system, a modified Zeiss PMQ2/3 spectrophotometer is used to take three diamond reflectance measurements at 412 m, 420 nm and at the lowest reading around 416 nm. The three readings are then fed into a calculator whose internal program computes the effective area of the diamond's 415.5 nm absorption band (the principal cause of colour in Cape series diamonds). The resulting figure is then used as a direct indication of the diamond's colour grade. The DGL system is used in the Independent Gemstone Testing Laboratory, London and in the Australian DGL laboratory in Sydney.

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5 Refractive index. Birefringence. Optical character and dispersion

Refractive index by immersion and microscope methods. Critical angle refractometers. Polariscopes and konoscopes. The table spectrometer.

For identification purposes, perhaps the most important single piece of information about a gemstone is its refractive index. The reason for this is that, for most gems, the R.I. is a very precise figure, measurable to three places of decimals, and readily repeatable. Because of the precision and constancy with which refractive indices can be measued, gems which look alike but have only a small difference in R.I., can be separated with ease (e.g. natural and synthetic spinel, pink tourmaline and topaz).

Before dealing with the instruments designed to measure the R.I. of a gemstone, a brief description will be given of alternative measuring techniques.

APPROXIMATION OF R.I. BY IMMERSION

When a white colourless gemstone is immersed in a liquid having an R.I. close to that of the gem, it virtually disappears, and even if the gemstone has a body colour, its facet outlines will become indistinct. This provides a method of approximating a stone's R.I., as the stone can be immersed in turn in a series of small pots or dishes containing liquids having various refractive indices.

The R.I. of the stone will be near to that of the liquid or liquids in which the stone's outline appears hazy.

A useful immersion 'comparator' has been devised by David Wilkins[1]. This consists of a small metal sample holder (20 mm × 13 mm) into which is set a diamond (R.I., 2.42), a 'high' zircon (R.I., 1.96), a synthetic sapphire (R.I., 1.76), a synthetic spinel (R.I., 1.727) and a clear quartz (R.I., 1.54), The R.I. of each stone is embossed in the metal alongside the stone for ease of identification. If the sample holder is immersed in toluene (R.I., 1.49) or benzene (R.I., 1.50) with the stone under test, a close approximation to the unknown stone's R.I. can be obtained by matching its degree of 'invisibility' to that of the sample stones.

APPROXIMATION OF R.I. USING THE BECKE LINE METHOD

While this technique was originally developed for the measurement of powdered samples of unknown minerals (or inclusions), it was adapted by R. K. Mitchell for use with faceted gemstones. The method uses a microscope with light-field illumination and a partially closed iris. The magnification of the microscope should be ideally in the region of 30× to 40×.

The stone under test is placed, table facet down, in an immersion cell containing a liquid of known R.I. The immersion cell is then placed on the microscope stage, and positioned so that the pavilion facet edges are visible. If the focus of the microscope is lowered from the liquid down into the stone, and the facet deges change in appearance from light to dark, then the R.I. of the stone is *greater* than that of the liquid. If, however, the opposite occurs, and the facet edges turn from dark to light, then the R.I. of the stone is *less* than that of the liquid. By progressively changing the liquid in the immersion cell for one of a higher or lower R.I., a close approximation of the stone's refractive index can be obtained.

MEASUREMENT OF R.I. USING A CALIBRATED MICROSCOPE

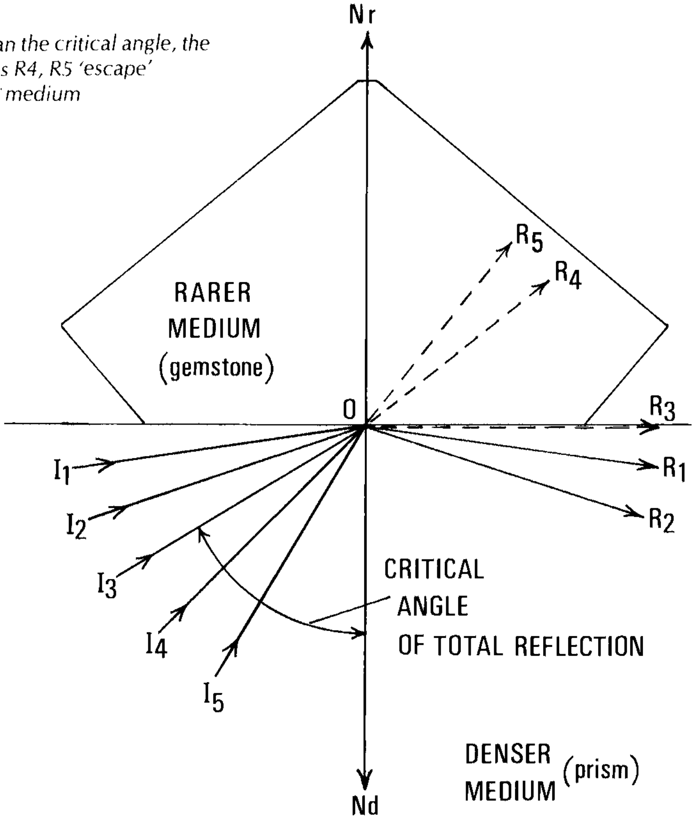
This method depends on the use of a calibrated focus adjustment or a dial gauge on the microscope. (See Hans-Günter Schneider and Eickhorst microscopes in Chapter 3.) The microscope is first used to measure the apparent depth of the gemstone under test, and is then used to measure its real depth. The refractive index of the stone can then be calculated by dividing the real depth by the apparent depth, (in a doubly refracting stone this will be the R.I. due to the ordinary ray).

When using this method, the gemstone is positioned on the stage of the microscope with its culet facing down, and table facet facing up (a small piece of plasticine can be used to secure the stone in this position). The microscope is carefully focused on the surface of the table facet, and the position of the focus setting read from the scale. The microscope is then focused down through the stone until the face of the culet is sharply defined, and a second reading is taken. If the second reading is subtracted from the first, the result will be the apparent depth of the gemstone. The real depth can be gauged by moving the stone to one side and focusing the microscope on the surface of the stage. If this third focus reading is subtracted from the first, the result will be the real depth of the stone (alternativley, this can be measured directly off the stone by means of a Leveridge gauge). The real depth can then be divided by the apparent depth to obtain the R.I. of the stone. Measurement of a gem's R.I. by this method is limited to an accuracy of plus or minus one per cent, even for large stones, but has the advantage that it can be used to determine the index of high R.I. stones such as diamond and zircon.

CRITICAL ANGLE REFRACTOMETERS

To understand the operation of this important class of instrument, we must first consider the effect of varying the angle of incidence with which a light ray, travelling through a dense medium, meets the surface of a rarer one (*Figure 5.1*). Initially, if we start with the ray I_1 inclined at a large angle to the normal, it will be reflected back totally from the interface of the two

Figure 5.1
At angles less than the critical angle, the incident light rays R4, R5 'escape' through the rarer medium



mediums as R_1, and will obey the laws of reflection (angle I_1.0.Nd equals angle Nd.0.R_1).

As the angle of incidence is progressively reduced, the incident rays (I_2) will continue to be reflected back through the dense medium (R_2). Reflection of the incident ray will continue until the critical angle of total reflection I_3.0.Nd is reached, when the incident ray will cease to obey the laws of reflection, and will obey Snell's laws of refraction. At the critical angle, the refracted ray R_3 will, in fact, travel along the interface between the two media, and will therefore be refracted away from the normal by 90 degrees.

As the angle of incidence is decreased still further the rays I_4 and I_5 will pass into the rarer medium and be refracted away from the normal N_r.

If the dense medium forms part of an optical instrument, and the rarer medium is in fact a gemstone, the ray of light passing through the dense medium will be reflected back from the surface of the gemstone over an arc of incident angles, but will 'escape' through the gemstone at angles of incidence equal to and less than the critical angle. This critical angle is dependent upon the refractive indices of the two mediums, and as the R.I.

of the dense medium is constant, it can be related directly to the R.I. of the gemstone (i.e. the greater the stone's refractive index, the greater will be the critical angle).

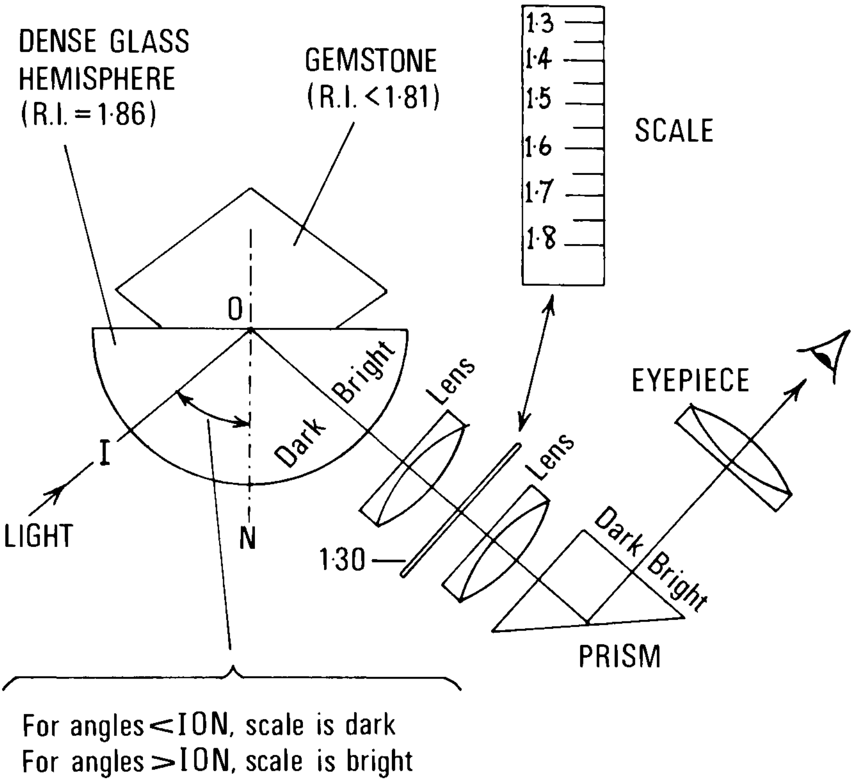
$$n = n_1 \text{ sine } ION,$$

where n is the unknown R.I., n_1 is the R.I. of the denser medium and ION is the critical angle.

The refractometer uses the phenomenon of critical angle to measure a gemstone's R.I., but a reading will only be obtained if the stone's refractive index is lower than that of the dense medium or glass in the refractometer (in practice this is limited still further by the R.I. of the contact fluid, which is explained later). This glass consists of a hemisphere, or truncated prism, made from optically dense glass, which has a high lead-oxide content giving it an R.I. in the region of 1.86.

The basic construction of the critical angle refractometer is shown in *Figure 5.2*. Light rays arriving at the interface between the gemstone and the glass hemisphere, and having an angle of incidence less than the

Figure 5.2
Components and ray path for the critical angle refractometer



critical angle *ION,* are not reflected into the lens system, while those having a greater angle than *ION* are. When these reflected rays pass through the calibrated translucent scale, this results in a brightly lit section (reflected rays) and a dark section (rays lost through gemstone). The shadow line between the two sections acts as a cursor and indicates the refractive index of the gem on the scale.

Use of contact fluid

Because of the difficulty in obtaining a good optical contact between a gemstone facet and the refractometer glass, use is made of a contact fluid having a high R.I. (1.81 for standard Rayner instruments). A drop of this contact fluid is placed in the centre of the glass, and the gemstone lowered onto it. The fluid effectively excludes any air from the gem/glass interface, and because of its high R.I. does not interfere with the gemstone readings (a faint shadow edge, caused by the fluid, can be seen at 1.81 on the scale). The fluid itself normally consists of a saturated solution of sulphur in methylene iodide plus tetraiodoethylene (see also fluids used with diamond-table and Krüss refractometers).

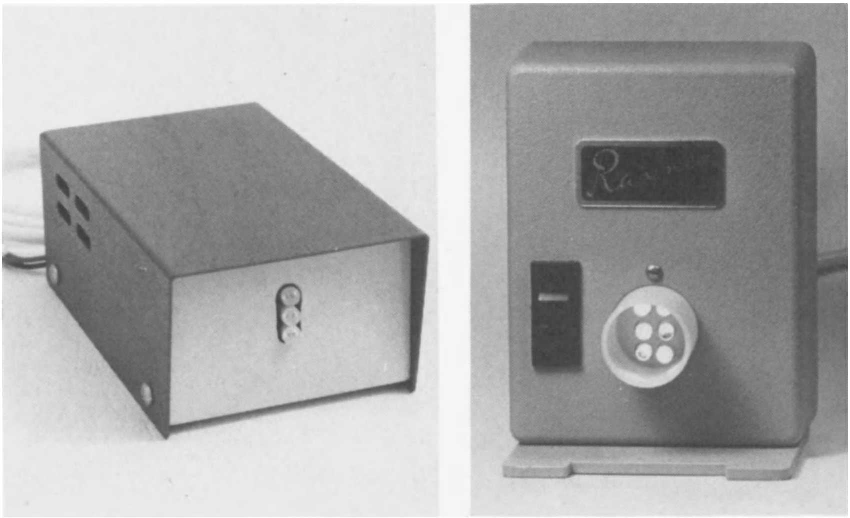
As the refractometer glass is relatively soft, precautions have to be taken to avoid scratching it. Even the application of the contact fluid must be made with care, particularly if this is done with a glass rod dropper. Such a dropper should only be brought close enough to the glass to transfer a small drop of the fluid, and should not be allowed to touch the glass. The amount of fluid placed on the glass should be limited, ideally, to a drop 2 to 3 mm in diameter, and when the test is completed, this should be removed carefully from the glass (and from the gem) using a paper tissue. If the fluid is allowed to remain on the glass it may tarnish its surface.

To prevent a deterioration in the performance of the refractometer, any stain should be carefully removed by wiping the glass with methylene iodide, and if this fails, by polishing it with jewellers rouge. If the instrument is not going to be used for a long period, it is good practice to apply a thin film of Vaseline to the surface of the glass. This can be removed subsequently by the use of a special non-flammable liquid called 'Rayclean' (available from Gemmological Instruments Ltd). This liquid is particularly suitable for cleaning the glass 'table' of a refractometer (as well as gemstones) as it dries off rapidly without leaving residues.

Sources of illumination

When using the refractometer, it is necessary to provide a source of illumination. If the illumination used is polychromatic light (i.e. a lamp, or daylight), then the shadow edge, as viewed on the scale, will be less distinct, as it will consist of a band of prismatic colours. Because the refractive index for gemstones is defined in terms of yellow monochromatic light having a wavelength of 589.3 nm, it is necessary, when using a

Figure 5.3
Two mains-operated refractometer light sources using high-intensity yellow light-emitting diodes (LEDs) whose emission peak is centered on 585 nm. Left: The Solite unit (Davenport and Waterhouse Instruments Ltd). Right: The Rayner unit (Gemmological Instruments Ltd)



'white' light source, to take the R.I. reading against the yellow/green boundary in the coloured shadow edge. Alternatively, all but the yellow portion of the shadow edge can be filtered out by fitting a deep yellow filter in front of the refractometer eyepiece.

For accurate work it is best to use a monochromatic sodium light source. Unfortunately, the cost of a suitable sodium lamp unit is comparable to the price of the refractometer. For those who are prepared to improvise, a usable source of sodium light can be produced by simply placing some common salt (sodium chloride) on a piece of wire gauze and heating it in a welding torch/butane flame. Alternatively, less expensive yellow-filter and interference-filter light sources can be used (see the OPL and Eickhorst Modul 1 and 2 units in this Chapter). Another source of refractometer illumination is provided by yellow light-emitting diodes (LEDs), as used in the Rayner unit (*Figure* 5.3, $120) and the Solite unit (*Figure* 5.3, $80), the latter manufactured by Davenport and Waterhouse Instruments Ltd. (See also the Eickhorst GemLED refractometer in this chapter, and the experimental LED light source in Chapter 13.)

Using the critical angle refractometer

Once the refractometer and the source of illumination are set up ready for use, and the stone to be tested has been thoroughly cleaned, a small drop of contact fluid should be placed in the centre of the refractometer glass and the stone lowered, table facet down, onto it. It may be necessary, while viewing the shadow edge, to move the stone carefully across the face of the glass in order to get the clearest result. If the stone is doubly refractive, it will also be necessary to rotate the stone to observe the maximum separation of the resulting twin shadow edges. As it is only too easy to scratch the surface of the glass during these operations, a Rotagem attachment (*Figure 5.4*) was designed by Dean S. M. Field and developed by Rayners for use with their instruments. This device facilitates the rotation of the gem in a controlled manner. ($46).

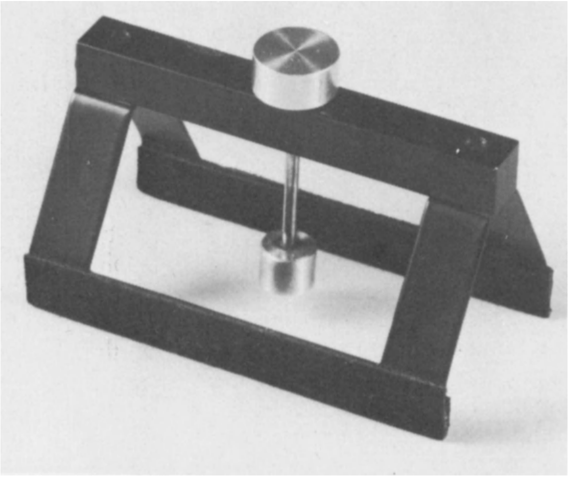


Figure 5.4
The Rotagem refractometer attachment gives controlled rotation of the gem under test (Gemmological Instruments Ltd)

The twin shadow edges of a doubly refracting gemstone can normally be seen quite easily, but occasionally, where the difference between the two refractive indices is small, the separate edges may be more difficult to determine. In these circumstances, a polarising filter attachment can be fitted over the eyepiece. The rotation of the filter will permit first one shadow edge and then the other to be perceived, and even if these are close together, the alternate appearance and disappearance of the individual edges can be detected.

As double refraction can be accurately measured with the refractometer, the relationship between the two refracted rays often provides valuable diagnostic information.

If, as the stone is rotated on the refractometer, one shadow edge (due to the 'ordinary' ray) remains stationary, while the other (due to the 'extraordinary' ray) moves away to a position of maximum separation, and then returns, the stone can be identified as being doubly refractive (birefringent), and its optical character as being uniaxial.

If the moving shadow edge has a higher R.I. reading than the fixed one, the stone is optically positive, and if it has a lower R.I., it is optically negative.

If, however, two shadow edges are visible, and they *both* move as the stone is rotated, this identifies the stone's optical character as biaxial. If the higher-reading edge moves more than halfway from its highest-reading position towards the lowest-reading position of the other edge, the stone is optically positive. If the lower-reading edge moves more than halfway towards the higher edge, the stone is optically negative.

Distant vision method

While it is practical to measure the R.I. of any faceted gemstone within the range of the refractometer (provided that a flat facet face of reasonable size is accessible), a problem exists if the stone has very small facets, or has been fashioned into the rounded cabochon form. To overcome this problem, Mr. . B. Benson, Jr. (of the G.I.A.) devised a technique which is called the 'distant vision' method in the UK, and the 'spot' method in the USA.

The method varies slightly with the types of refractometer, but for the Rayner models consists first of coupling the rounded surface of the cabochon to the refractometer glass with the smallest possible spot of contact fluid. This is done by placing a drop of the fluid on a flat surface, and then lightly touching the drop with the surface of the cabochon, which will then pick up the minimum quantity required. The cabochon is next placed on the refractometer glass with its spot of fluid acting as an optical coupler.

The refractometer scale is then viewed with the eye positioned in line with the eyepiece, but 12–18 in (30–45 cm) away from it. By careful positioning of the line of sight, it should be possible to see (superimposed on the limited section of scale now visible) a small 'bubble', which is the spot of liquid coupling the cabochon to the glass. If the line of vision is now moved slowly up and down, the bubble will be seen to change from dark to light. When it is dark, the bubble will correspond to a scale reading below the R.I. of the stone, and when it is light, the scale reading will be higher than the stone.

If the line of vision is carefully adjusted until the bubble is divided exactly into two halves (one light and one dark) this will correspond to the scale reading for the R.I. of the stone. Unfortunately, when the eye is focused for best observation of the bubble, the scale is out of focus, and some mental dexterity is required to hold the bubble in its bisected position and simultaneously to read the R.I. from the scale.

Note:

If a polarising filter is placed over the eyepiece and rotated while making a 'distant vision' reading, the junction of the light and dark sections of the bubble will jump within the spot image if the stone is doubly refracting. The amount of this movement will give an indication of the size of the double refraction.

SPECIAL REFRACTOMETER VERSIONS

Two variants of the standard high-density glass refractometer (now no longer produced) were devised by Anderson and Payne. One variant replaced the refractometer glass with spinel to give a more open scale between 1.3 and 1.68, thus permitting more accurate readings. The other benefit gained from the use of spinel is that its dispersion more nearly matched that of the majority of gemstones, and this gave a sharper shadow edge in white light than does the standard version. It is also harder than glass. The other variant used blende (with an R.I. of 2.37) in place of the glass to expand the high reading end of the scale.

The diamond table refractometer

A third variant, used diamond (R.I. of 2.42) and is also no longer manufactured. The diamond-table refractometer was also proposed by Anderson and Payne[2], and a diamond prism (using abutting glass prisms to transmit the incident and reflected light) was fashioned for the first experimental refractometer from a 6.632 carat 'Silver Cape' stone donated by the Diamond Corporation[3]. The final weight of the finished prism was 2.505 carats.

A number of diamond-table refractometers were made by Rayners, the typical diamond prism dimensions being 7.5 × 3.67 × 4.2 mm deep with a weight of 1.54 carats. With this instrument, refractive index readings can be taken from 1.59 to 2.03, enabling the R.I. of zircon, the garnets and sphene to be measured. Perhaps even more important than the wide R.I. range are the other advantages that diamond offers, i.e., its greater optical purity, its hardness (which enables it to take a much higher polish) and its ability to resist both abrasion and chemical attack from the contact liquid.

Unfortunately, to take advantage of the extended R.I. range, the contact fluid must have a similarly high R.I., and this involves the use of unpleasant fluids such as West's solution (with an R.I. of 2.05), which consists of a skilled mixture of phosphorus and sulphur in methylene iodide. Because of the presence of phosphorus in the solution, its residue is spontaneously combustible and it must therefore be handled with care.

The Strontium titanate table refractometer

Yet another variant, this time a more recent one, is the instrument developed by Siber and Siber of Switzerland, and manufactured by Krüss. This version of the critical angle refractometer uses a strontium titanate prism (with an R.I. of 2.41), and in place of the conventional contact fluid it employs a special brown viscous paste having an R.I. of 2.22. To make the contact paste flow as a liquid, both it and the strontium titanate prism are electrically heated, and this enables the range of the instrument to be extended to 2.21 (see under ER602 Riplus refractomer in the following notes).

Now that the main techniques and precautions associated with the use of the refractometer have been described, we can discuss the various commercial models that are available.

COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

Dialdex refractometer (Rayner/Gemmological Instruments Ltd)

(*Figure 5.5*)

This is the latest development of the Model S Rayner refractometer. It uses a fixed dense-glass truncated prism (in place of the hemisphere shown in *Figure 5.2*) and has a large aperture at the rear for the injection of light from an external source. A hinged cover is provided which, when closed over the gem being tested, excludes all extraneous light. The R.I. range covered is 1.40 to 1.81; a pull-out eyepiece is provided for focusing.

The main difference between the Dialdex and the standard Model S is, as its name implies, the provision of a calibrated dial on the right-hand side of the instrument. When measuring the R.I. of a gemstone, this dial, which is coupled to a sliding-ribbon type straight edge, is rotated to make the straight edge coincide with the shadow edge on the scale. The R.I. reading is then read from the calibrated dial (which facilitates the testing of cabochons by the 'distant' method).

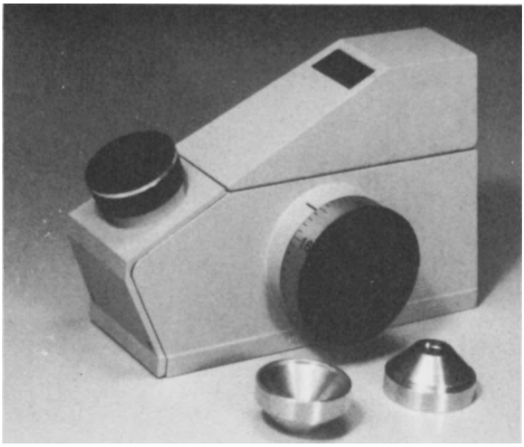


Figure 5.5
The Rayner Dialdex refractometer (Gemmological Instruments Ltd)

This method of measurement also has the advantage of allowing the user to concentrate on the position of the shadow edge without having to read (and then remember) a scale position at the same time. The R.I. value set on the dial can then be evaluated at leisure, and readings to an accuracy of 0.001 can easily be estimated. The instrument can be provided with a deep yellow glass filter and a polarising filter. (Model S and the Dialdex both $250).

Variants of the Rayner refractometer, using spinel, blende and diamond (as devised by Anderson and Payne) have been described earlier in this chapter.

Also available for use with Rayner refractometers is the sodium monochromatic light source. This comprises a sodium lamp with ballast choke, starter and on/off switch, housed in a metal case, which also acts as a base for the refractometer. The unit can be supplied for use on either 110–130 V, 60 Hz or 210–240 V, 50 Hz mains. ($300. Spare lamp $140).

Monolite refractometer light source (OPL/Gemological Instruments Ltd)

The OPL Monolite light source (*Figure 5.6*) uses a quartz halogen lamp whose output is channelled from the base unit through an adjustable height column to an interference filter centered on 589 nm. The unit can be supplied for use on 110 V or 240 V, and a special dual voltage model is available. ($120).

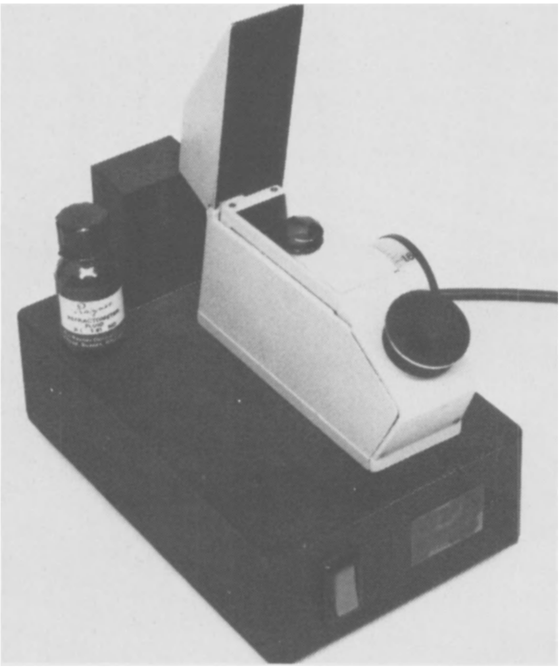


Figure 5.6
The Monolite refractometer light source uses a quartz halogen lamp and an interference filter (OPL/Gemmological Instruments Ltd)

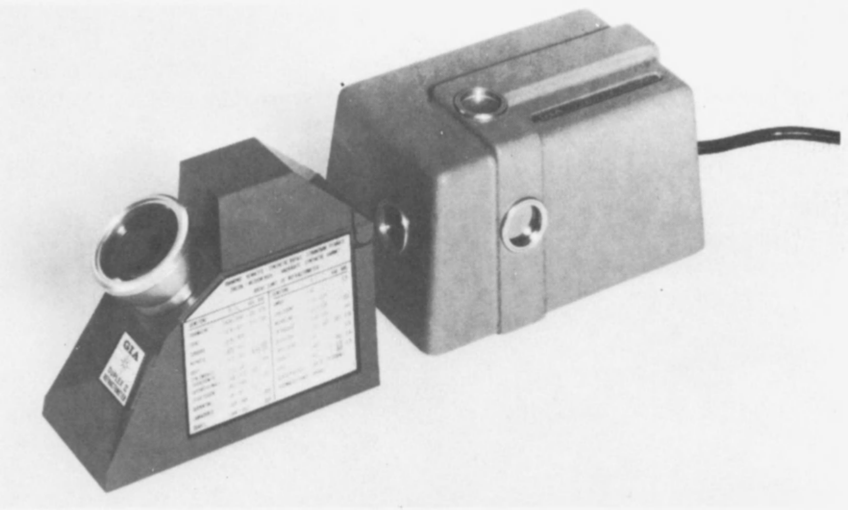
Duplex refractometers (GIA)

The original Duplex instrument is claimed to be the first to have been developed specifically to measure the R.I. of small faceted stones and cabochons, as well as large faceted stones. The instrument was designed by L. B. Benson Jr., K. M. Moore and G. M. Johnson, and employed a large slotted section of a hemicylinder in place of a hemisphere. It was fitted with a moveable mirror (instead of a pivotable eyepiece) to enable all of the scale length to be examined.

In the latest model, Duplex II, the instrument has been redesigned in order to dispense with the moveable mirror, and, like the Rayner, the entire scale length is now visible through a fixed eyepiece. The range covered is 1.35 to 1.80, and the instrument is provided with a polarising filter. ($190).

A utility lamp (*Figure 5.7*) can be used to provide a source of light for the refractometer. This lamp is provided with three outlets; a monochromatic yellow light, or an alternative white light (for use with the refractometer), plus a second vertically positioned white light for use with a dichroscope. ($160).

Figure 5.7
The Duplex refractometer (Gem Instruments Corporation)



ER601 refractometer (Krüss)

This instrument covers an R.I. range of 1.30 to 1.81, with scale gradations of 0.01 which allow readings to be made to an accuracy of 0.001, and is fitted with a 589 nm interference filter. A polarising filter is supplied for the eyepiece. ($361).

The ER601 can be mounted on a base unit BM611 which contains a high intensity filament lamp illumination source. The lamp's brightness level can be adjusted by a control on the front of the base unit. The unit is designed for 220 V, 50 Hz mains. ($181).

ER602 Riplus refractometer (Krüss) (*Figure 5.8*)

Using a strontium titanate prism and a special contact paste (Riplus Kleber), this instrument covers the range of 1.79 to 2.21. ($688).

The contact paste has an R.I. of 2.22, and only becomes sufficiently fluid to act as a contact liquid when it is heated to 40°C. An electrically heated recess in the top of the refractometer's mounting plinth is provided for the bottle of contact paste, and with the unit switched on keeps the paste in its liquid state. The strontium titanate prism is also heated by an electrical element, which is energised by a mains transformer in the unit's plinth.

This plinth, BM610 ($272), also contains a sodium light source, as the high dispersion (0.190) of the prism would otherwise produce colour fringing and loss of sharpness of the shadow line, even if used with an interference-filter light source.

When switching the unit on from cold, it takes approximately 15 minutes for the paste and refractometer prism to reach their operating temperature. Using the plastic dispenser supplied with the paste, a small quantity of the contact 'liquid' is then applied to the centre of the prism table and spread out to form a 2 to 3 mm dia. disc. The gemstone to be tested is placed on the paste and pressed down firmly to squeeze out any surplus material and thus produce the thinnest possible contact layer.

Figure 5.8
The ER602 Riplus refractometer (Krüss)

After each stone is tested it is necessary to remove the contact paste from both the stone and the prism table using, for example, cotton wool swabs soaked in methylene iodide. Although it takes a little while to become adjusted to the somewhat slower test procedure necessary with the ER602 Riplus refractometer, it is possible to measure refractive indices and double refraction as accurately as with a standard refractometer. It is particularly useful for measuring the refractive index of high R.I. gems such as YAG, zircon, sphene and cubic zirconia.

Warning – The Kleber paste contains arsenic tribromide, a toxic and corrosive chemical. Contact with the paste should be avoided. Any material on the body should be removed immediately by thorough scrubbing with water. The greatest danger is from ingestion, and this possibility is greatly reduced by not eating or smoking when using the material.

Refractometer Type RF1 (Schneider)

This instrument is a Japanese model, and covers a range of 1.30–1.80. Focusing is by means of a pull-out eyepiece, and a separate polarising filter is provided. ($432).

The Schneider light source consists of a plinth unit (for the refractometer) which has a projector lamp assembly mounted by means of a pivotable arm from its rear face. The lamp assembly is fitted with a monochromatic 589 nm (5890 Å) interference filter, and incorporates an adjustable iris. The low voltage lamp is fed from a separate transformer/control box which has a variable intensity control. The unit is designed for operation from 220 V, 50 Hz mains. ($255).

Topcon refractometer (R. Rubin/GAAJ)*(Figure 5.9)*

This is a Japanese instrument. It is designed particularly to measure the R.I. of cabochons and small faceted stones, as well as those with large facets. The range covered is 1.30 to 1.81; polarising filter is supplied. ($531).

Modul 1 refractometer/polariscope unit (Eickhorst)*(Figure 5.10)*

This unit is a combined refractometer and polariscope designed to match other Eickhorst instruments in a range employing the same module styling. Independent controls are provided for the polariscope lamp, and for controlling the intensity of the refractometer light source. The top analyser filter of the polariscope is rotateable, and the bottom filter is protected by a rotary glass gemstone table. ($759).

Figure 5.9
The Topcon refractometer (R. Rubin/GAAJ)

Figure 5.10
The Modul 1 unit is a combined refractometer and polariscope unit (Eickhorst)

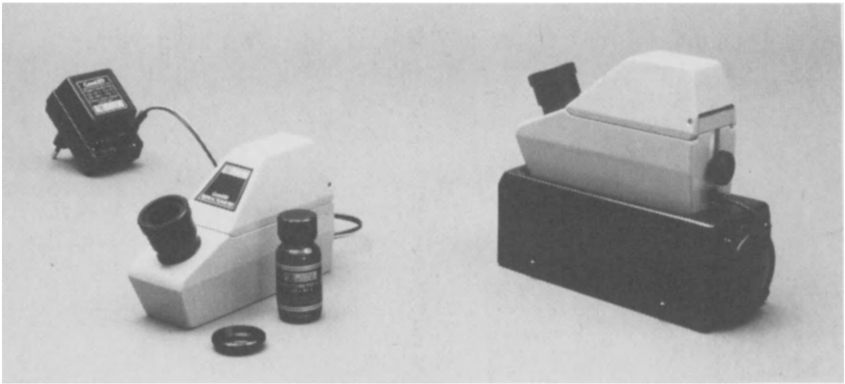
Modul 2 refractometer/polariscope unit (Eickhorst)

This is similar to Modul 1, but is provided with a base unit on which an existing Topcon, Rayner or Gem Instruments Corporation refractometer can be mounted. The 55-watt quartz iodide lamp is fitted with a 589 nm interference filter. ($509).

GemLED refractometer (Eickhorst) (*Figure 5.11*)

This is a self-contained refractometer and light source which operates via a mains plug power supply unit from 110 V or 220 V, 50/60 Hz. The light source consists of three high-intensity yellow light-emitting diodes (LEDs) whose emission response is centered on 590 nm. The LEDs are mounted close to the refractometer prism (*Figure 5.11*), and their light output can be varied via a control at the rear of the instrument. ($441). A battery

Figure 5.11a
The GemLED (Eickhorst)



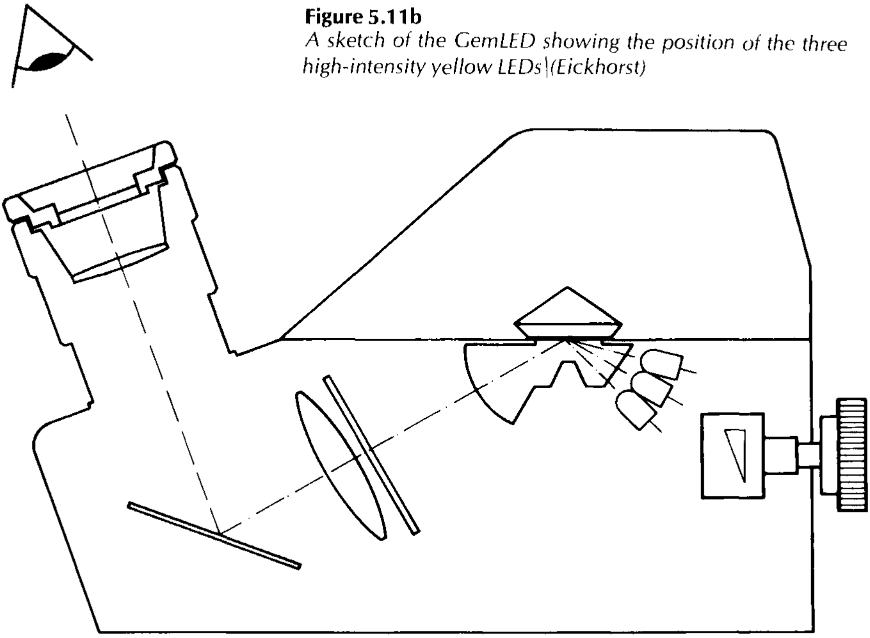


Figure 5.11b
A sketch of the GemLED showing the position of the three high-intensity yellow LEDs\(Eickhorst)

pack/refractometer stand is available ($45), and can be fitted with a rechargeable battery unit (complete with built-in charger) or a standard dry battery.

Although the emission response of the LEDs contains some red and green components, colour fringing is not apparent, and because of the high level of light available, it is possible to use a polarising eyepiece filter to improve shadow-edge contrast with doubly-refracting stones, a feature not always possible with external LED units.

Shimazdu refractometer (Nihon Hoseki-Kizai Co. Ltd)

This is a standard refractometer which is supplied complete with contact fluid, polarising eyepiece filter and xlene detergent cleaning liquid. ($273).

Gemstone – refractometer ER606 (Krüss) (*Figure 5.12*)

This unit comprises a plinth which contains a refractometer (covering the range 1.30–1.81), a mains-operated filament lamp for the source of illumination and a receptacle for the bottle of contact liquid. The filament lamp is under-run to achieve an operational life in the region of 5000 hours, and operates from a 220 V, 50 Hz mains supply. ($250).

POLARISCOPES AND KONOSCOPES

Although the critical angle refractometer is unsurpassed in its ability to reveal and measure single and double refraction in a gemstone, it is sometimes sufficient simply to know that a stone is isotropic or anisotropic. For this uncomplicated diagnostic test the polariscope comes into its own.

There are several versions of the instrument, but most of them use the following three basic components:

1. A light source (usually built-in).
2. A protected polarising filter over the light source (which also acts as a test platform for the gemstone).
3. A second polarising filter through which the stone is viewed.

The gemstone is placed on the lower filter (which is protected from damage by a glass cover plate), and the top filter is rotated into the 'crossed' position where the plane polarised light from the bottom filter is blocked or 'extinguished' by the top filter. If the stone is rotated through 360°, and is a doubly refracting gem, it will show four distinct positions (at 90° intervals) where it will transmit light (i.e. it will 'rotate' the plane polarised light from the lower filter through 90° so that it passes through the top filter). If the stone remains mainly dark when rotated, it will either be an amorphous or an isotropic (cubic) material.

Figure 5.12
The Krüss ER606 is a combination unit containing a refractometer and a filament-lamp light source

However, it is still possible that the stone could in fact be birefringent, and yet remain dark when rotated. This would happen if the stone was positioned so that the plane polarised light passed through it in a direction which was parallel to an optical axis. For this reason, a stone should be examined in at least two directions before deciding that it is singly refracting.

Some singly refracting stones, such as diamond and synthetic spinel, occasionally show some indication of birefringence when tested on the polariscope. When this happens, it is never as clearly defined as the four-fold change in light transmission seen in a doubly refracting stone. It is called 'anomalous double refraction', and is caused by internal strain in the gemstone. The anomalous double refraction seen in glass or 'paste' gems is usually quite distinctive, and appears as a strong cross-pattern of dark lines.

If a cryptocrystalline substance (e.g. chalcedony) is placed on the polariscope and rotated, it will appear uniformly bright in any position. This is due to the random orientation of the many minute crystals or fibres of which the gemstone is composed.

Polariscopes use relatively inexpensive plastic polarising sheet, but, before this material was available, Nicol prisms were used to produce polarised light. A Nicol prism comprises two sections of optically clear calcite (Iceland spar) which are cemented together with Canada balsam. Light entering the prism is split into two plane polarised rays. The refractive index of the balsam layer is such that it causes total reflection of the 'ordinary' polarised ray, while allowing the 'extraordinary' ray to pass through. Plastic polarising sheet contains myriads of microscopic crystals which transmit light with minimum absorption only when it is vibrating in one plane, and are optically opaque to rays which are polarised at right-angles to this plane. To protect the soft plastic polarising sheet, it is often sandwiched between plates of glass.

A variation of the polariscope is the konoscope. The konoscope function is for the determination of the optical axes in a gemstone, and in this configuration, the instrument employs a special converging lens between the two polarising filters. The top filter is set for extinction, and the gemstone is rotated in the fingers at a distance of approximately 15 mm from the converging lens until its optic axis appears. This optic axis will appear perpendicular to the light path as an interference pattern.

The following commercial polariscopes are examples of the various forms in which this versatile instrument can appear.

Rayner polariscope (Gemmological Instruments Ltd) (*Figure 5.13*)

This incorporates a rotatable glass table which also protects the lower filter. The top filter is adjustable, and can be rotated into the transmission or the extinction position. An aperture is provided in the front of the instrument so that the built-in light can also be used as a refractometer light source.

The instrument can be supplied for operation from either 110 V, 60 Hz or 230 V, 50 Hz mains. ($140).

Illuminator polariscope (Gem Instruments Corporation) (*Figure 5.14*)

In this instrument, the top polarising filter can be rotated and set for either extinction or 'in-line' tests. As with the Rayner model, the built-in light can also be used as a source of illumination for a refractometer. ($103)

Polariscope P1 (Hans-Günter Schneider)

This is a basic polariscope with a built-in light source and a gemstone platform over the lower polarising filters. ($148).

Polariscope Konoscope PK3 (Hans-Günter Schneider) (*Figure 5.15*)

An instrument designed to serve both as a polariscope and as a konoscope.

When used as a polariscope, the converging lens is swung out of the light path. ($360)

Konoscope sphere A-140 (Hanneman)

This is a strainless plastic sphere mounted on a rod for use with a polariscope in visualising optic axes. ($5).

Pocket polariscope (R. Rubin) (*Figure 5.16*)

Comprises two units, a battery powered illuminator fitted with a polarising filter, and a hand loupe also fitted with a filter. ($75).

Figure 5.13
The Rayner polariscope
(Gemmological Instruments Ltd)

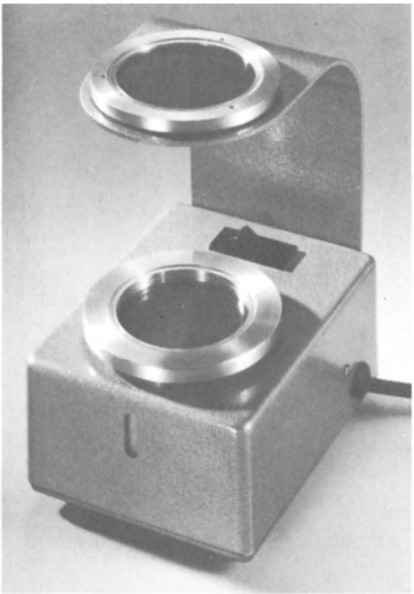


Figure 5.14
The Illuminator polariscope
(Gem Instruments Corp.)

Figure 5.15 (Bottom left)
The Polariskop/Konoscope PK3
(Hans-Günter Schneider)

Figure 5.16 (Bottom right)
A pocket polariscope
(R. Rubin & Son)

GAAJ gem polariscope

This is similar to the GIA polariscope in that the top filter can be rotated for extinction or 'in-line' tests, and the built-in light can be used as a source of illumination for a refractometer. ($114).

Polariscope/Konoscope PK10/KN10 (Krüss) (*Figure 5.17*)

This instrument is a combined polariscope and konoscope, but can be supplied without the konoscope lens attachment. ($186; with konoscope attachment $286).

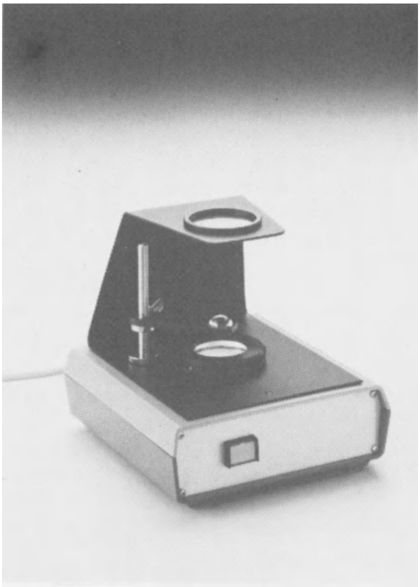
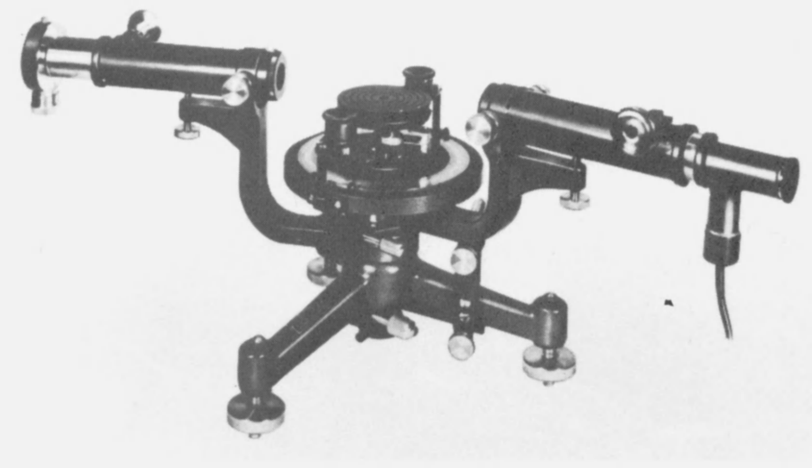


Figure 5.17
Polariscope/Konoscope PK10/KN10 (Krüss)

THE TABLE SPECTROMETER (*Figure 5.18*)

This consists of a fixed collimator (for producing a narrow beam of parallel light rays from a monochromatic source), a table (for supporting the specimen), and a radially-mounted telescope viewer having an eyepiece fitted with cross wires. The position of the telescope, relative to the collimator, can be read off a scale on the table by means of a vernier scale. For gemmological purposes, the table spectrometer is particularly useful for measuring the R.I. of gemstones which are above the range of the critical angle refractometer.

Figure 5.18
A Lang table spectrometer (Krüss)



Provided that the gemstone has suitable facets, which can serve as the two faces of a prism, its refractive index can be determined to better than three places of decimals. This is done by first measuring the angle between the two facet faces, and then measuring the angle of minimum deviation of the 'prism'. As long as the angle between the prism faces is not greater than twice the critical angle for the gemstone, there is no upper limit to the refractive index that can be measured.

The angle between the two selected prism facets is measured as follows. First adjust the collimator for as fine a slit as possible by focusing it on the telescope cross wires. Then position the gemstone in the centre of the table so that its prism facet edges are exactly vertical, and so that the light from the collimator falls upon the adjacent faces of the prism whose angle is to be measured. Turn the telescope round until the image of the collimator slit, reflected from one of the faces of the prism, is centered in the telescope cross wires. Take the reading of the telescope vernier (*V*). Then turn the telescope to view the image which is reflected from the other prism face, and again record the reading of the telescope vernier (*W*). The prism angle (*A*) is equal to half the difference between the two vernier readings,

$$A = \frac{V-W}{2}$$

To measure the prism's angle of minimum deviation, first remove the gemstone from the table and take a direct vernier reading (*X*) of the slit of the collimator as seen through the telescope. Replace the gem on the table so that it receives the light from the collimator on only one of its prism faces. This light will be refracted by the prism and the telescope should be positioned to receive the refracted image. The slit will in fact be dispersed into a spectrum, and the cross wires of the telescope can be aligned on the red part of this spectrum.

The next operation is to find an angular position for the prism that will result in the smallest angle of deviation between the incident light from the collimator and the refracted light picked up by the telescope. To do this, look through the telescope, and rotate the gem about its vertical axis so that the refracted spectrum moves towards the line of incident light emerging from the collimator; follow this image round by rotating the telescope. A point will be reached where the image will appear to stop and then to reverse its direction. In the position where the image stops, adjust the telescope position so that cross wires again coincide with the red section of the spectrum. Read the telescope vernier (Y).

The angle of minimum deviation is obtained by subtracting the direct reading X from the refracted image reading Y.

Angle of minimum deviation = $X-Y = B$
The refractive index for the gem is then;

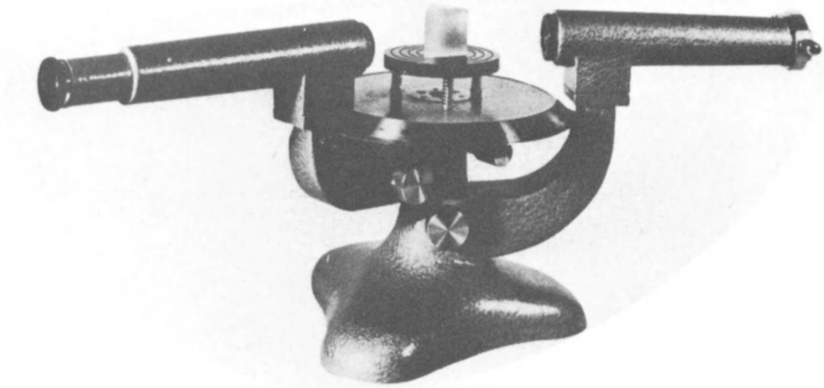
$$\text{R.I.} = \frac{\text{sine}\ \dfrac{(A+B)}{2}}{\text{sine}\ \dfrac{A}{2}}$$

Because there is usually only one suitable orientation of the gemstone on the spectrometer table, it is only normally possible to obtain a correct R.I. for the ordinary ray of uniaxial gem minerals. With biaxial gem minerals the R.I. reading may be anywhere between that of the ordinary and extraordinary ray, as these both vary with orientation. For isotropic minerals of course no such problem exists. Dispersion can be measured by using a monochromator, or suitable interference filters, to find the R.Is at 686.7 nm and 430.8 nm.

While the Lang spectrometer (*Figure 5.18*) is an expensive, though handsome, instrument, and is usually found in research laboratories, the relatively simple student version shown in *Figure 5.19* is generally adequate for gemmological purposes. A modern version of the table spectrometer can be seen in *Figure 5.20*. This is the Krüss gemstone spectroscope KL1302 ($1536) which can be used as previously indicated for the determination of R.I. and dispersion (see Chapter 8 for further details).

In practice, it is not necessary to resort to the complications of the table spectrometer in order to determine the dispersion of a gemstone. As dispersion is the difference between R.I.s obtained at the B and G Fraunhofer wavelengths of 685.7 nm (red) and 430.8 (blue), it is possible to use the critical angle refractometer for these measurements. This is done by using a monochromator to produce light approximating to these

Figure 5.19
A student table spectrometer (Krüss)



wavelengths. The difference between the two resulting refractive indices can then be modified by a factor which allows for the dispersion of the measuring prism to give the dispersion of the stone. The practicality of the method has been successfully proved by B. Suhner[4] who has used two interference filters to produce monochromatic light at 480 nm and 654 nm. These, coupled with a good light source, have enabled dispersion values to be calculated to an accuracy of 0.001 on a Topcon refractometer.

Figure 5.20
The gemstone spectroscope KL1302 can be used as a table spectrometer for measurement of R.I. and dispersion (Krüss)

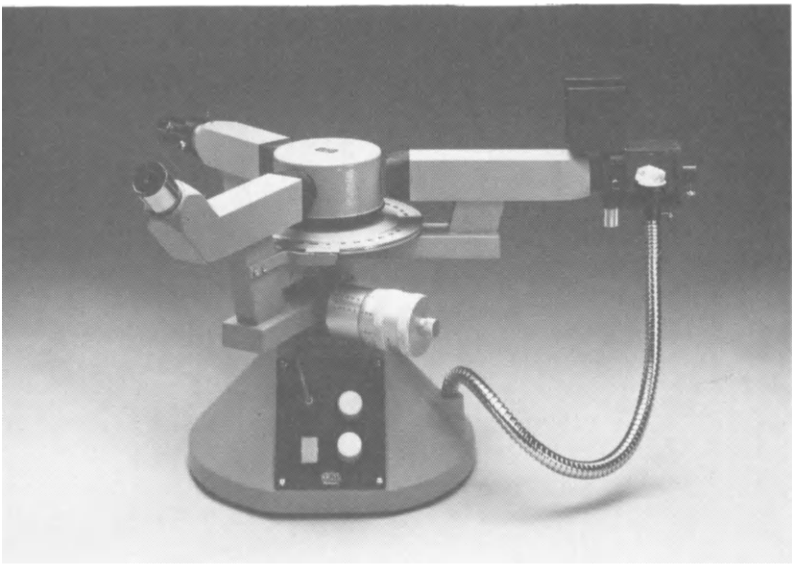


Table 5.1

Manufacturers or Suppliers (see Appendix A for Addresses)	*Refractometers*	*Polariscopes*	*Table spectrometer*
Rayner/Gemmological Instruments Ltd.	●†	●	
Davenport and Waterhouse Instruments Ltd	†		
Gem Instruments Corp	●	●	
Krüss	●	●*	●
Schneider	●	●*	
.Rubin	●	●	
Topcon/Rubin	●		
Rubin		●	
GAAJ	●	●	
Nihon Hoseki-Kizai Co Ltd.	●	●	
Eickhorst	●†	●	

* Combined Polariscope/Konoscope
† LED light source

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6 Relative Reflectivity

Relationship between refractive index, lustre and relative reflectivity. Relative reflectivity meters.

In Chapter 1, the lustre of a gemstone was defined as being the characteristic quality of surface polish produced on the facets of that stone. To expand this definition, it can also be said that the amount of light reflected back by the stone is directly related to the excellence of its polish, and as this approaches perfection, it represents the characteristic lustre for that class of gem mineral. Such a lustre, which can be described qualitatively as adamantine, vitreous, resinous, etc., is dependent on several factors such as the surface structure of the mineral, its hardness, and its refractive index.

The first reflectivity instrument for gemstone identification (comprising a visual optic comparator) was built by L. C. Trumper in 1959 and earned him the Gemmological Association's Research Diploma. Unfortunately, the instrument was too complex for general manufacture and was not exploited commercially.

RELATIVE REFLECTIVITY METERS

In recent years, many electronic reflectivity-type instruments have appeared on the market (one of these was described as an electronic refractometer and was calibrated in R.I. values). These instruments indicate the classification of a gem by measuring the ratio between the intensity of an incident light ray, directed at the surface of the gemstone, and that of the ray reflected back from the stone.

In relating this ratio to the refractive index of the gemstone, Fresnel's simplified equation, describing the reflectivity of a transparent isotropic mineral in air, states that for normal incidence,

$$R = \frac{I}{I_o} = \frac{(n - \mathrm{a})^2}{(n + \mathrm{a})^2}$$

where R = the gem's reflectivity;
I = the intensity of the reflected beam;
I_o = the intensity of the incident beam;
n = the R.I. of the gem;
a = the R.I. of the surrounding medium (normally air).

If the equation is multiplied by 100, this will give the percentage of perpendicular incident light which is reflected back from the surface of a gemstone (e.g. substituting $n = 2.42$ for diamond, $n = 1.55$ for quartz and $a = 1$ for air, a figure of 17% is obtained for diamond, and 4.6% for quartz).

However, in practice it is quite difficult to irradiate a gemstone's surface at normal incidence (i.e. perpendicular) and simultaneously measure the reflected beam (also at normal incidence). For practical purposes therefore, the angles of incidence and reflection are usually offset from the normal.

For this reason, and because of considerations such as birefringence, absorption, surface finish and cleanliness (none of which are allowed for in the equation) the result, in terms of refractive index, can only be an approximation, and may often be quite misleading. In addition, the use of infra-red light at 930 nm (9300 Å) for the incident beam in electronic reflectivity meters makes the results even less acceptable (refractive index readings for gemstones are quoted in terms of yellow monochromatic light at 589.3 nm, 5893 Å).

It is therefore more accurate to regard these electronic instruments as Relative Reflectivity meters, and to interpret their readings as a measurement of a gemstone's lustre.

Another difficulty in relating the reflectivity of a gem to its refractive index when using this type of instrument occurs when the gem has an appreciable amount of dispersion, i.e. the difference in the index of refraction as measured at the B and G Fraunhofer wavelengths of 686.7 nm and 430.8 nm. The refractive index of a gemstone is conventionally given in terms of sodium light at 589.3 nm. If a gemstone has very little dispersion, its index of refraction will not be very much different if measured at other wavelengths. However, for gems having appreciable dispersion, wavelengths above or below 589.3 nm will modify the measured refractive index considerably.

At the infra-red wavelength of 930 nm, as used in reflectivity meters, the 'R.I.' readings of strontium titanate (R.I. = 2.41) and diamond (R.I. = 2.42), for instance, will be found to be well separated, with strontium titanate reading much lower than diamond because of its greater dispersion. In this case, the separation of two almost identical refractive indices works to advantage when using infra-red reflectivity to distinguish strontium titanate from diamond.

When electronic reflectivity meters were first introduced, and were reviewed by Webster in the Journal of Gemmology[1,2,3], the test results obtained varied from impressive and repeatable to inaccurate and variable. While the manufacturers of these instruments warned users of the essential requirements of cleanliness and good surface polish in the gem under test, it was tempting to test first and explain away misleading results afterwards.

The concept that this was a viable method of reading a stone's refractive index was also firmly fixed in the mind of many users. It was some time before the concept of relative reflectivity, or lustre, as a valid measurement in its own right began to be considered. One of the chief protagonists of the idea of a quantitative scale of lustre was Dr. W. W. Hanneman (who invented the 'Jeweler's Eye' and 'Diamond Eye' relative reflectivity meters and the 'Lustermeter').

It was argued by Dr. Hanneman[4,5], that as the frequent low readings produced by a gemstone on a relative reflectivity meter were caused by imperfections, scratches or dirt on the polished surface of the stone, the instrument was, in fact, reading the actual lustre of the stone's facet and not the potential lustre of which the mineral was capable (and certainly not the stone's R.I.).

One of the obvious uses of the relative reflectivity-type meter is the identification of stones whose R.I. is beyond the range of the critical angle refractometer. In this respect it can be a valuable aid when testing for diamond and its simulants.

COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

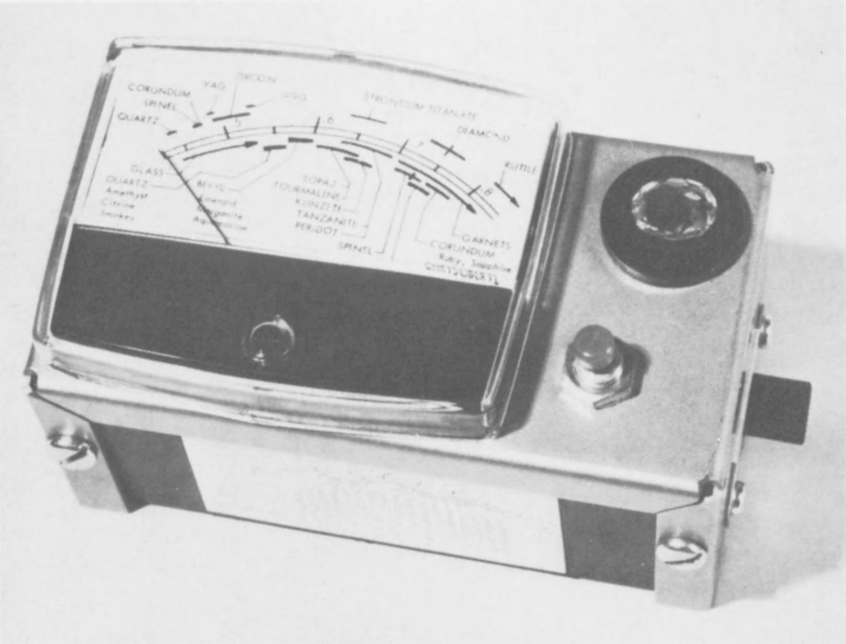
The 'Jeweler's Eye' (Hanneman Specialties Inc/Gemmological Instruments Ltd/Glenjoy/Rubin) (*Figure 6.1*)

This relative reflectivity meter, whose circuit diagram is shown in *Figure 6.2*, is a pocket-sized instrument, and consists basically of a gallium arsenide light emitting diode (LED), which produces a beam of infra-red light at 930 nm (9300 Å), a photo-diode, which detects the infra-red light reflected from the surface of a gemstone and a meter which indicates the amount of reflected light. As the incident light is constant, it is only necessary to measure the intensity of the reflected light to obtain comparative readings of relative reflectivity. ($205).

A two-position switch and two pre-set resistors enable the intensity of the incident light to be adjusted in order to calibrate the two meter ranges. The lower range starts with glass at the bottom end, and covers garnets at the top end. This range is calibrated using spinel as a standard. The upper range starts with quartz at its bottom end and covers rutile at its top end. This range is calibrated using diamond as a standard. The meter scale is marked in bands showing the range of possible reflectivity readings for particular gem minerals. In addition to the scale fitted to the meter, two further substitute scales are provided. These are mounted on the side and bottom of the instrument, and cover additional groups of gemstones.

To prevent extraneous light from entering the gemstone under test and increasing the intensity of the light reaching the photo-diode, an opaque

Figure 6.1
The 'Jeweler's Eye', showing a gemstone on the test platform (top right). Two substitute meter scales, fixed to the front and base of the instrument, cover additional groups of gemstones. A bench version of the 'Jeweler's Eye' is also available. (Hanneman Specialties)



cap is placed over the stone on the test platform. The instrument is powered by a small 9 V battery, which provides energising current for the LED, the photo-diode and the meter. Although a voltage stabilizer is fitted, an occasional calibration check should be made (with correction adjustments to the pre-sets if necessary) as the batter voltage falls. Despite the simplicity of this unit and its unsophisticated internal construction, it is capable of producing reliable results provided that the requirements of cleanliness and facet condition are kept in mind. As with all dual range reflectivity meters, the top range (covering diamond and its simulants), is probably the most useful.

The Diamond 'Eye' (Hanneman Specialties Inc./Gemmological Instruments Ltd/GfD) (*Figure 6.3*)

This is a pocket-sized unit which uses the same circuit as the 'Jeweler's Eye', but has only one range, and is calibrated in L_H (Hanneman lustre) values for diamond (4), and the diamond simulants YAG (1), GGG (2), strontium titanate (3) and cubic zirconium oxide (labelled as ^{3}Z). ($160).

Figure 6.2
Circuit diagram of the 'Jeweler's Eye'. The positions of the photo detector and the infra-red lamp on the lamp/detector assembly are shown in the sketch beneath the circuit

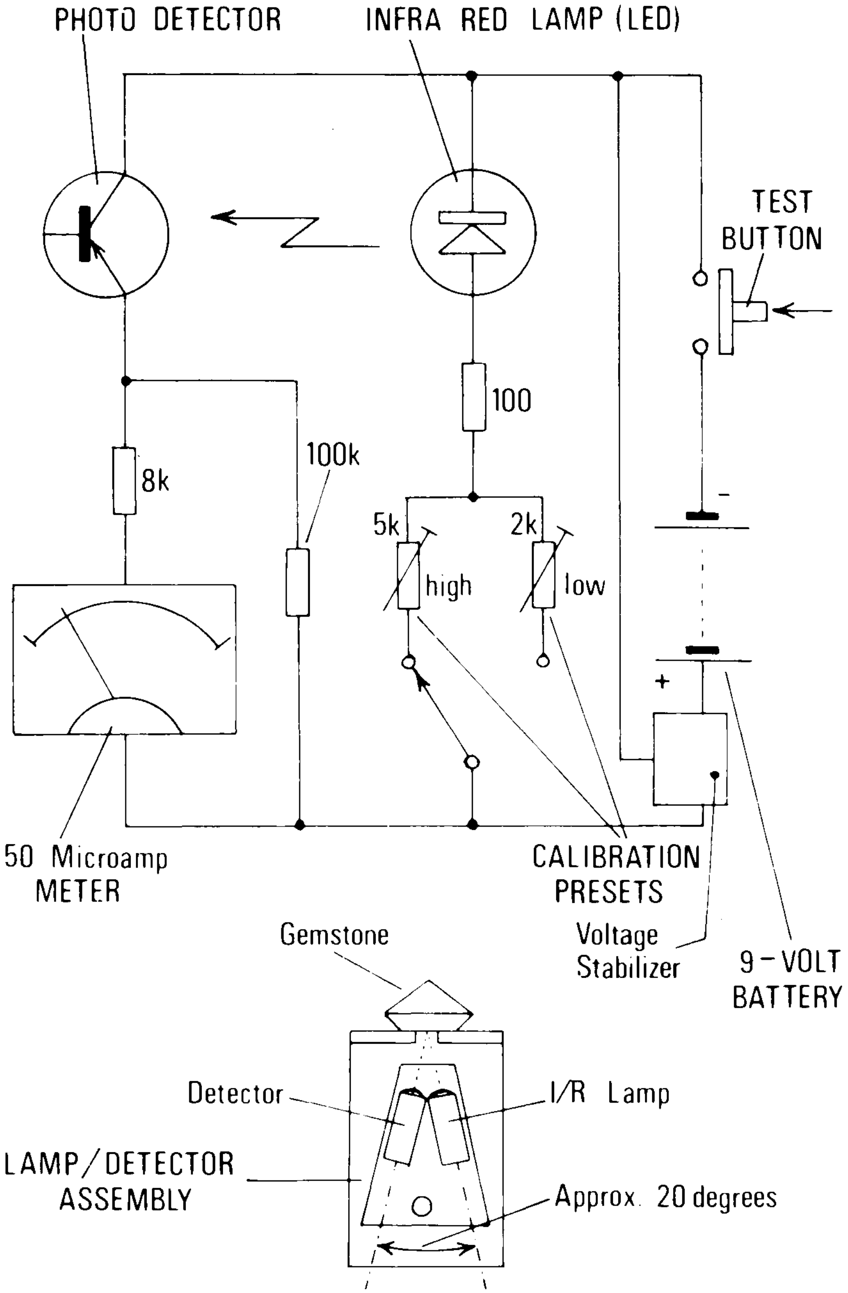
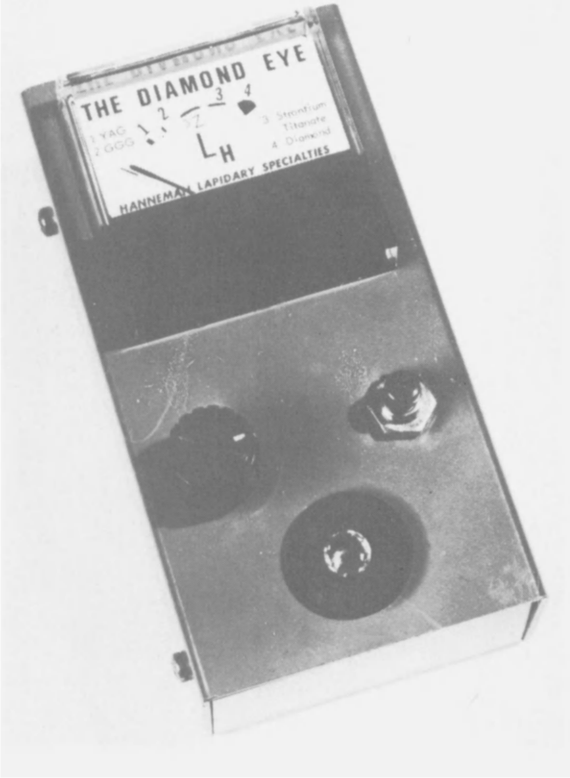


Figure 6.3
The 'Diamond eye' uses the same circuit as the 'Jeweler's Eye', but is only calibrated for diamond and the diamond simulants YAG, GGG, Cubic Zirconium Oxide (labelled ³Z) and Strontium Titanate (Hanneman Specialties)

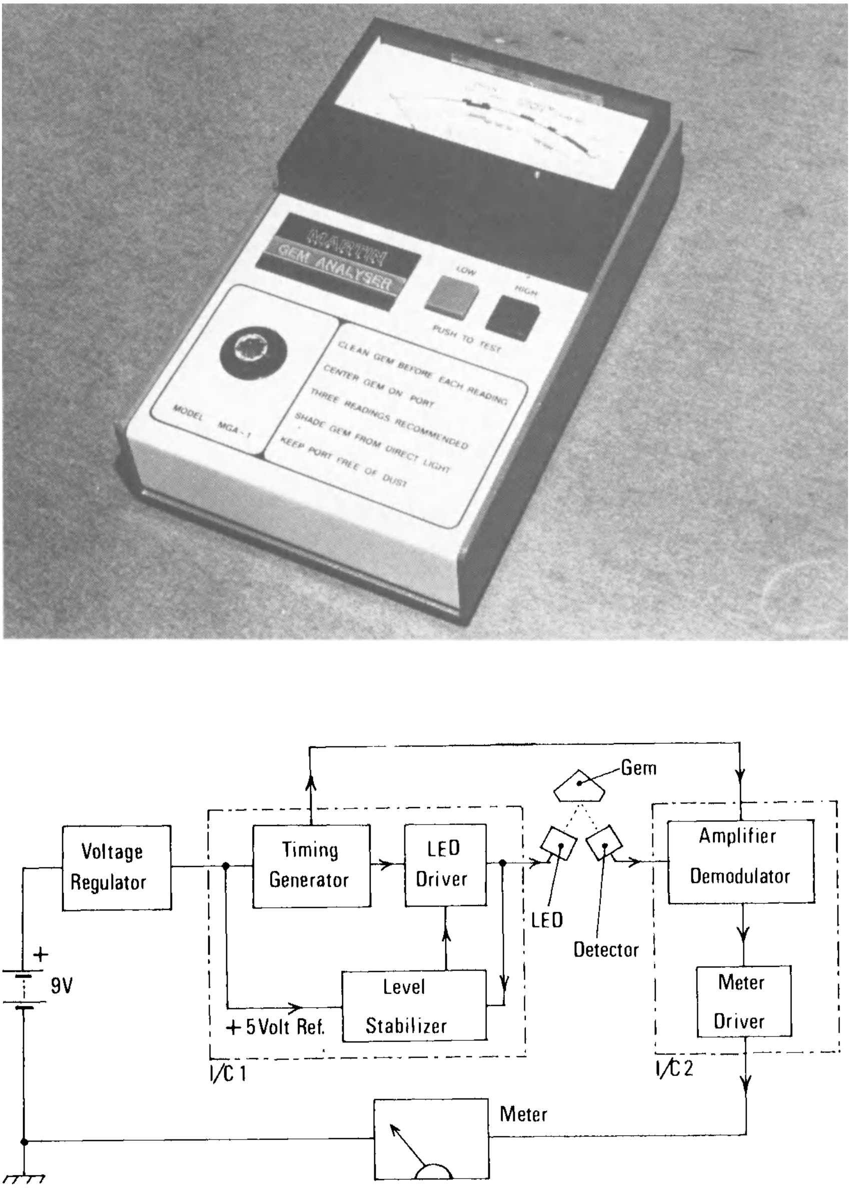


Martin MGA-1 gem analyser (Martin Precision Instrument Co/Eickhorst) (*Figure 6.4*)

This is a two-range instrument covering glass to corundum on the low range and YAG to rutile on the high range. Although the manufacturer states that the analyser measures refractive indices, the meter scale is directly calibrated in gemstone names. The test platform is designed to accommodate stones of over half a carat in size, and although it uses pulsed infra-red it is advisable to shield the stone from extraneous light when testing in strong ambient lighting[6].

The unit is powered, via a voltage stabiliser, from a 9 V battery, (*Figure 6.5*), thus eliminating battery voltage drift (between the limits of 7–10 V) as a source of error. The electronics consist of six transistors and two integrated circuit packages, and as these are sealed against moisture and thermally compensated, the instrument is capable of working accurately over a temperature range of 0 to 55 degrees centigrade, and a relative humidity range of 0 to 95%. For these reasons, no externally-accessible calibration adjustment is provided. All the electrical and electronic components are mounted on a printed circuit board of professional standard. ($440 including case).

Figure 6.4
The 'Gem Analyzer'. Both the high and low meter ranges are calibrated to show the range of expected readings for the principal gemstones (Martin Precision Instrument Co.) (below) Block diagram of 'Gem Analyzer' circuit showing the two integrated circuits I/C1 and I/C2



The Diamond Checker (Culti/Geshiro/Krüss) (*Figure* 6.5)

This is a single-range unit designed specially for distinguishing diamond from its many simulants. The unit is well constructed using top quality components, and can be battery or mains operated (the latter via a plug-in adaptor). A red lamp indicates when its on/off switch is in the 'on' position. A second push button enables the battery condition to be checked on the meter. ($380 including Perspex top cover and carrying case).

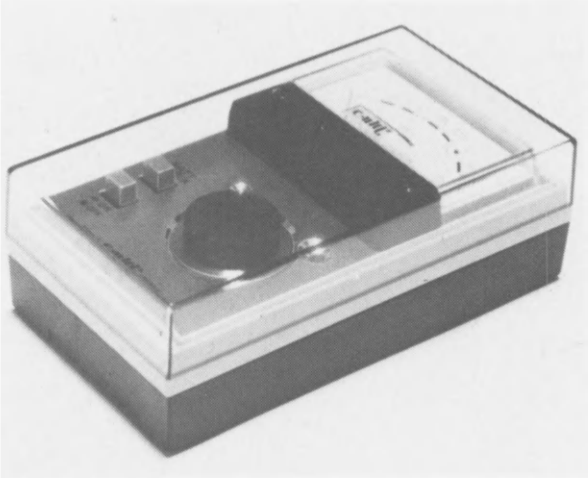


Figure 6.5
The Diamond Checker is a single-range unit designed specifically for the identification of diamond and its simulants

The test platform is fitted with a circular plinth which can be removed to reveal the cone-shaped tip of the test aperture, a feature particularly useful when checking stones which are recessed in their mount.

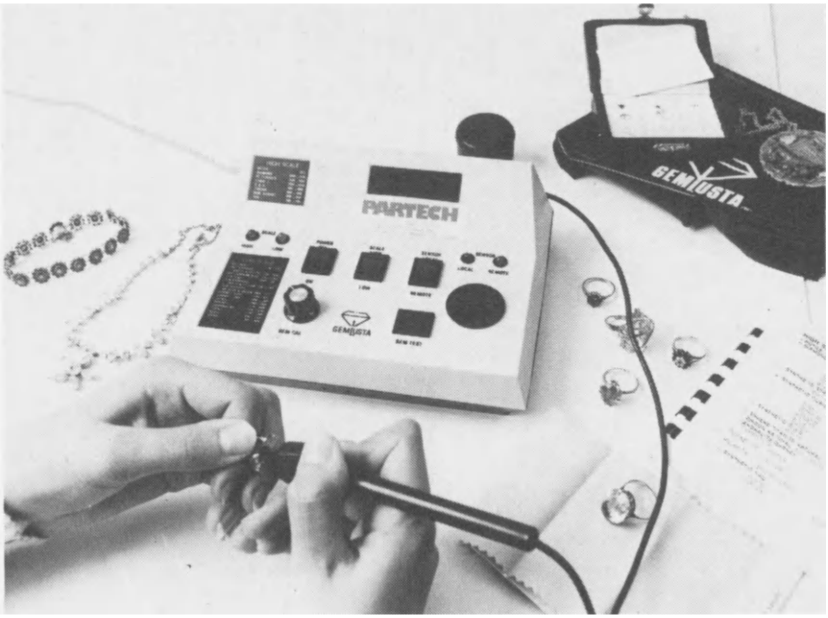
Although it is advisable to shield the rear of a gemstone with the hand when testing in strong ambient light conditions, the Diamond Checker uses a pulsed infra-red lamp and detector, and as a result its readings are unaffected by quite high levels of lighting.

Gemlusta 400X (Gemtronics/Partech Electronics Ltd) (*Figure* 6.6)

This is an innovative unit which uses both a test platform and a hand-held reflectivity probe. The 400X has seen several improvements since it was first introduced, the main one being an expanded four-digit scale which gives greater discrimination between gems having similar reflectivities. A calibration synthetic sapphire is supplied with the unit. ($860).

The expanded scale on the 400X has highlighted an interesting difference in reflectivity between synthetic and natural rubies and sapphires. This difference is indicated on the 'Low Scale' table of readings printed on the front control panel, where figures for natural ruby are quoted at 1,790 to 1,945, while those for synthetic ruby are significantly lower at 1,680 to 1,787. Similar differences are quoted for natural and synthetic sapphire.

Figure 6.6
The Gemlusta 400X can distinguish between machine-cut synthetic corundums and hand-polished natural sapphires and rubies by the differences in their reflectivities (Gemtronics)



Tests with rubies and sapphires confirm the ability of the 400X to distinguish between natural and synthetic corundums. However, after conducting phase-contrast inspections of the gem's surface on a microscope, it was confirmed that these readings are in fact caused by differences in the polish or lustre between machine-cut synthetics and hand-polished natural stones and are not therefore 100% reliable as a method of identification.

The hand-held probe has a top with a 45 degree cone-shaped profile which makes it possible to reach the table facet of recessed stones. Because of the difficulty in holding the probe at precisely right-angles to the facet of the stone, it is necessary to adjust its position until the highest output reading is obtained. The switches on the control panel are stiff in operation, and this draws attention to the lack of rigidity in the plastic control box housing. TheGemlusta 400X operates from 110 V or 240 V 50/60 Hz mains (via an 'in-lead' power supply unit).

The Gemlusta Mini (Gemtronics/Partech Electronics Ltd) (*Figure* 6.7)

The Gemlusta Mini is a battery-operated portable model employing the same hand-held probe unit as the 400X, but designed solely for the identification of diamond and diamond simulants. ($390).

Figure 6.7
The Gemlusta Mini is a single-range portable unit using a hand-held probe (Gemtronics)

Figure 6.8
The Italian-built Reflectometre uses an LED digital readout (Fraul)

The Reflectometre (Fraul/Rubin) (*Figure* 6.8)

This is a battery-operated Italian-built reflectivity meter, and was possibly the first instrument of this type to use a digital readout. It is a single-range unit designed primarily for the identification of diamond and its simulants. ($440).

The Gemsensor reflectivity meter (Daneng) (*Figure* 6.9)

The Gemsensor is a small unit using a liquid crystal display (LCD) for battery economy, and a hand-held reflectivity detector probe. The unit is a single-range model intended for use with diamonds and diamond simulants. The tapered end of the probe makes it suitable for use with recessed stones and can be used to test stones as small as five points (0.05 carat) in size. Two plastic accessories can be attached to the probe to provide a larger reference surface and a clamp for non-recessed and unmounted stones. Battery life is 100 hours. ($350).

Figure 6.9
The Gemsensor uses an LCD display and a hand-held probe (Daneng)

The Aldinger reflectivity meter (U. A. Aldinger) (*Figure* 6.10)

This was probably the first commercial reflectivity meter in which the LED/photo detector unit in the control box was linked via a bifurcated glass-fibre light guide to the hand-held probe[7]. ($455).

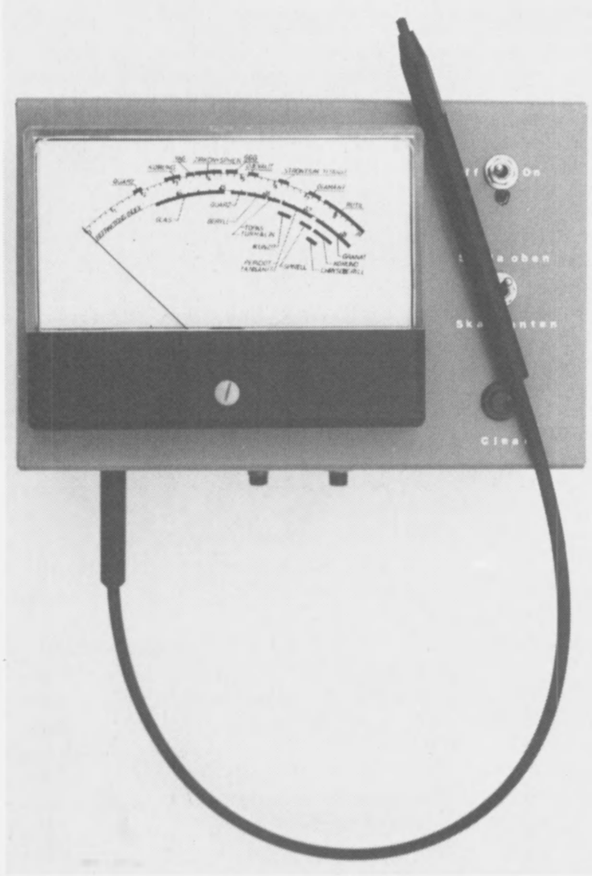


Figure 6.10
The Aldinger reflectivity meter uses a glass-fibre light guide probe to test recessed stones and cabochons
(U. A. Aldinger)

The second unusual feature of this unit is that the 1 mm diameter metal ferrule which terminates the light guide contains a miniature converging lens with a focal length of 1 mm. Before testing a gemstone, the instrument's 'Clear' button is pressed to reset the meter reading to zero. The test probe is then held at right-angles to the gemstone's surface, and slowly brought into contact with it. When the probe tip approaches within 1 mm of the stone's surface, the infra-red beam from the probe reaches its optimum focus and the reflected energy (as received at the detector end of the light guide) rises to a maximum.

The peak value of this reflected energy is automatically registered by the instrument's memory circuit to produce a latched (i.e. steady) meter reading. Because of the very small dimensions of the I-R beam at its focal point, the instrument is able to measure the reflectivity of curved as well as flat surfaces (e.g. cabochons).

The unit has two ranges, the upper one covering quartz to rutile, and the lower one glass to garnet. A pulsed I-R LED and photo detector are used to minimise interference from ambient lighting, and the power source is a re-chargeable battery. Thermal drift is compensated for by feeding the output of the detector into the memory circuit each time the 'Clear' button is pressed.

As with all hand-held reflectivity probes, the main problem is the alignment of the probe at right-angles to the gemstone surface. Before this skill is mastered, it is advisable to take several readings and select the highest one. Occasionally, with small stones in a close-set mount, a false high reading can be produced by the focal point of the I-R beam passing through the stone and the detector sensing the high reflectivity of the surrounding metal. This situation, however, can be anticipated by prior inspection.

The Tatsumi Diamond Tester (Nihon Hoseki-Kizai Co. Ltd)

The Diamond Tester is a single-range portable reflectivity meter covering gems in the R.I. range 1.70 to 2.60. A calibration stone and a light-excluding cap are provided. ($273).

The Gemlyzer (Eickhorst) (*Figure 6.11*)

The Eickhorst Gemlyzer incorporates two novel features. The first of these consists of a 30-element LED bar graph which replaces the conventional meter indicator. The second feature is the unusual design of the reflectivity test platform. This has a cap which can be unscrewed to give access to the light source and photo detector units so that they can be kept free from dust, an important requirement with reflectivity testers. The cap can also be replaced by one having space for the prongs of a mounted gemstone.

The row of thirty light-emitting diodes in the bar graph is numbered 0 to 30 and labelled with names of gemstones from quartz at 5 to rutile at 30. The unit can be operated via a mains adaptor or from internal batteries. ($268).

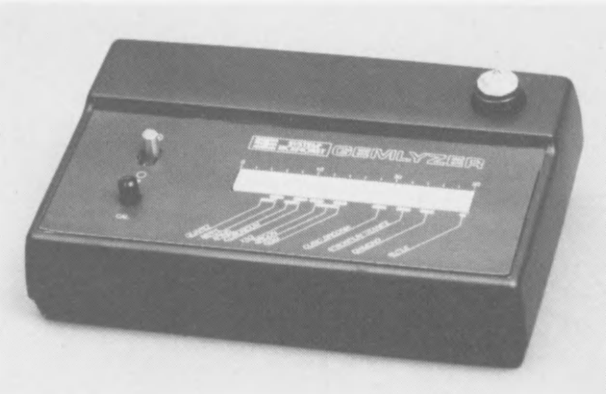


Figure 6.11
The Eickhorst Gemlyzer uses a 30-element LED bar graph in place of the conventional meter indicator

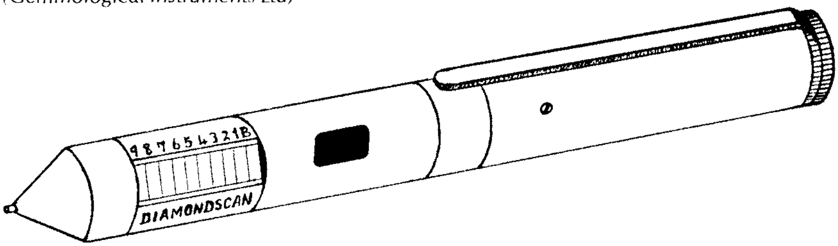
The Rayner DiamondScan (Gemmological Instruments Ltd) (*Figure 6.12*)

The DiamondScan is a breast-pocket size reflectivity instrument operating from a 6 V lithium manganese dioxide battery. The tester, which is designed for on-site use at auctions, etc., has a diameter of 18 mm and an overall length of 155 mm.

To enable the unit to test recessed diamonds and diamond simulants, a bifurcated glass-fibre light guide is used to couple the infra-red LED and photo-diode detector to a 0.75 mm internal diameter sensor tube at the tip of the unit.

The DiamondScan's compactness is achieved by using a row of ten red LEDs in place of the conventional meter, each LED indicating the reflectivity level of a specific stone. Calibration against a known diamond is achieved by means of a preset accessible through an aperture in the instrument's case.

Figure 6.12
The Rayner DiamondScan is a miniature breast-pocket unit using fibre optics and a 10-LED display scale to identify diamonds and diamond simulants, even when these are recessed (Gemmological Instruments Ltd)



When in use, the probe tip is placed squarely in contact with the gemstone's facet, and the angle of the gem adjusted to obtain the highest-reading, rutile being indicated nearest the probe tip at 9, and diamond the next highest at 8. Because the infra-red beam and the resulting reflected ray are virtually normal to the surface of the gemstone (the ideal conditions for meeting the requirements of the Fresnel formula), an occasional false high reading may be obtained from reflections off the metal backing of close-set stones. It is also important to shield the sensor end of the unit from ambient light. This can be done by placing the thumb and forefinger on opposite sides of the stone's pavilion while testing.

The DiamondScan's miniature printed circuit assembly includes two integrated circuits and a voltage stabilizer. The battery condition is verified by the first indicator (labelled B) in the row of ten LEDs, which (with the sensor tip shielded from light) continues to glow until the battery voltage falls below a preset level.

To ensure maximum battery life, the unit is only energised when its spring clip is pressed down on the case. A flexible dust cover protects the sensor tip and prevents spurious operation of the clip switch. Because of the small internal diameter of the sensor tip, the tester can be used to check diamonds and other stones down to at least five points (0.05 carat) in size. (Around $220).

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7 Specific gravity

Hydrostatic weighing method. Heavy liquid method. Specific gravity indicators. Specific gravity bottle.

There are few concepts that can be as clearly associated with one man as can specific gravity to the Greek scientist, mathematician and philosopher Archimedes. Although twenty-two centuries have passed since Archimedes formulated his Principle that a body immersed in a liquid experiences an upward force equal to the weight of the fluid it displaces, this simple law, to which the concepts of density and specific gravity are related, has become a diagnostic corner stone in the science of gemmology.

The importance of specific gravity to gemmology is due to the fact that the S.G.'s of the important gemstones are sufficiently separated and constant to make them unique and therefore confirmatory for the gemstones. The specific gravity, or relative density, of a substance is due in part to the atomic weights of its constituent elements, and in part to the compactness of the structure formed by these constituents. For example diamond, with its relatively light but compactly arranged atoms of carbon, has a higher specific gravity than quartz, with its heavier but more dispersed atoms of silicon and oxygen.

As there may be some confusion between the terms density and relative density or specific gravity, the following note should help to clarify matters.

The *density* of a substance, as measured in SI units, is its mass in kilograms per cubic metre. This is expressed mathematically as kg/m^3 or $kg.m^{-3}$. Using SI units, the density of diamond is, for example, 3.52×10^3 kg/m^3 (in the older c.g.s. units this was expressed as grams per cubic centimetre, or g/cm^3, and for diamond was $3.52 g/cm^3$).

The *relative density*, or *specific gravity* of a substance is the ratio of its mass over the mass of the same volume of water, and as it is a ratio, no units are involved. The S.G. for diamond is therefore the pure number 3.52.

Anyone who becomes interested in gemstones, and begins to handle them, is soon aware that between similarly sized stones, some feel appreciably heavier in the hand than others. For example, a zircon is twice as heavy as an opal of similar size. More precisely, one can say that their specific gravities differ.

By definition, it follows that to measure the specific gravity of an object it is necessary to determine its volume. This at first sight poses a considerable practical difficulty unless one is only dealing with perfect cubes or other regular geometric shapes whose volumes can be calculated from their measured dimensions.

However, one method of measuring an object's volume, and hence determining its specific gravity, is to use an Eureka can. This consists of a metal container fitted with an overflow pipe. The container is first filled with water until it just begins to flow out of the pipe. When the water level has stabilised and the overflow has ceased, an empty beaker is placed under the pipe and the object to be tested is gently lowered into the can. The volume of water which is displaced into the beaker then represents the volume of the object. This can either be measured directly in a vessel graduated in cubic centimetres, or, as the weight of water in grams is directly equal to its volume in cubic centimetres, it can be measured by weighing the water. (An even simpler, though less accurate, method is to drop the object into a graduated beaker and note the amount by which the water rises in the beaker).

The specific gravity of the object can then be calculated by dividing the volume or weight of the displaced water into the weight of the object.

$$\text{Specific gravity} = \frac{\text{Weight of object in grams}}{\text{Volume of displaced water in cubic centimetres}}$$

While this is a valid method of measurement for large objects, it is not accurate enough for gemstones because of their relatively small volume. However, three alternative methods, based on the Archimedean Principle, have been devised for the determination of specific gravity in gemstones.

Because of the convenient 1:1 relationship between its volume and weight (measured in cubic centimetres and grams), water is chosen as the standard when quantifying specific gravity. Specific gravity, therefore, is defined as being the ratio between the weight of the object, and the weight of an equal volume of pure water at 4°C (the temperature at which its density is at maximum). By definition, water has an S.G. value of 1.0.

HYDROSTATIC WEIGHING METHOD

As this method depends on precise weighing measurements, it should only be attempted on a high grade beam balance of the analytical type (as used for diamond and laboratory work). The balance sensitivity should be of the order of ±0.001 carat (±0.0002 gram). Top-pan balances, which sacrifice sensitivity for convenience, are not normally suitable for hydrostatic weighing because of their lower sensitivity and less adaptable construction.

The hydrostatic method is directly based on the Archimedean Principle that an object totally immersed in a fluid experiences an upward force equal to the weight of the displaced fluid. The method consists of weighing the gem to be tested in air, and then weighing it again while it is immersed in pure water.

As the method depends on very small differences in weight measurement, and as these differences are directly related to the size of the gemstone, reasonably accurate results can only be obtained with stones of two carats and upwards. Conversely, when weighing a large object, such as a carving, it is possible to obtain reasonable results even when using a spring balance and a pail of water.

By definition:

$$\text{S.G. of the gem} = \frac{\text{Weight of gem in air}}{\text{Weight of equal volume of water}}$$

By the Archimedean Principle this equation can be rewritten,

$$\text{S.G.} = \frac{\text{Weight of gem in air}}{\text{Weight lost by gem when immersed in water}}$$

$$= \frac{\text{Weight in air}}{(\text{Weight in air}) - (\text{Weight in water})}$$

or, $$\frac{A}{A - B}, \text{ at } 4^\circ\text{C}$$

where

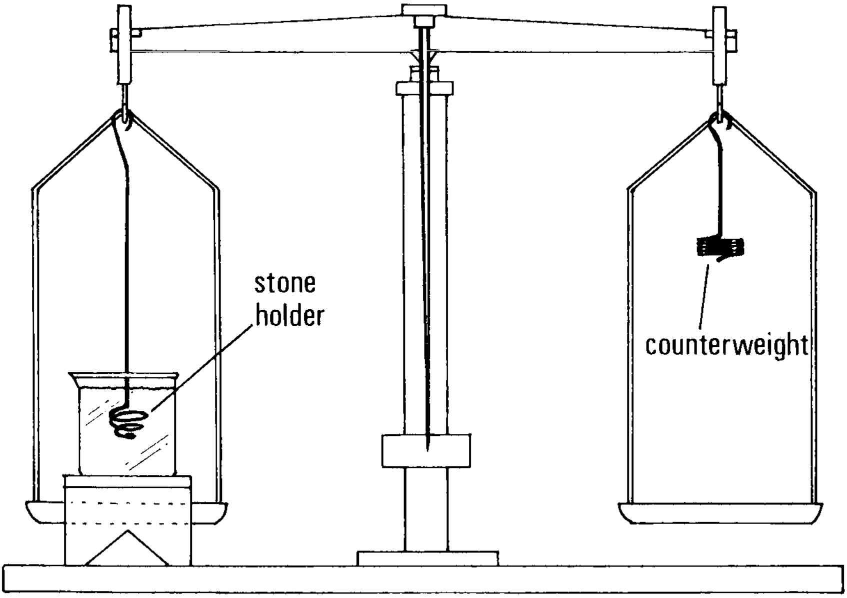
A = Weight of gemstone in air;

B = Weight of gemstone immersed in water.

For S.G. measurements the stone can be weighed in air in the normal way. To weigh the gemstone conveniently while it is immersed in water, a few accessories are needed (see *Figure 7.1*). First of all, a beaker of distilled (or purified) water is required, and this must be supported above the left-hand weighpan of the balance (using a wooden bridge or stool to span the pan without touching it). A wire support, which can be attached by a cord to the weighpan 'hanger' and used to suspend the gemstone in the water, must also be made. This can be fabricated from a length of 20–22 s.w.g. tinned copper wire to form a spiral basket.

The cord supporting it from the weighpan hanger should be fine gauge mono-filament nylon (not nylon braided glass yarn as this will absorb water by capillary action). Its length should be adjusted so that the basket is immersed in the water throughout the swing of the balance. Alternatively, the suspending cord can be dispensed with and the wire forming the spiral basket can be extended so that it can be hooked over the hanger (this may however reduce balance sensitivity as it will affect the free swing of the weighpan).

Figure 7.1
Sketch of beam balance, showing beaker of water supported over left-hand pan with gemstone holder immersed in water. The counterpoise is attached to the right-hand pan hanger



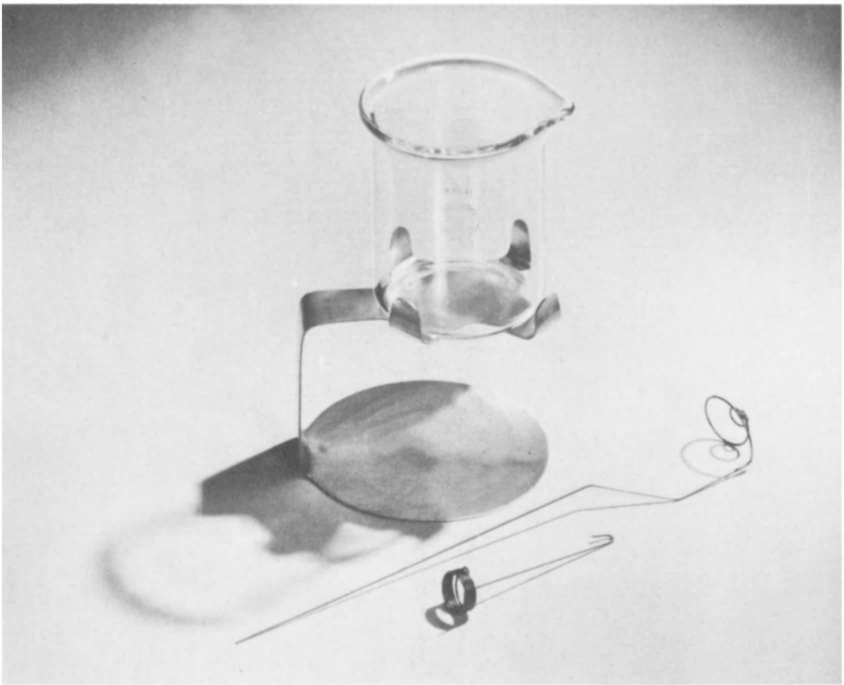
Finally, to simplify the S.G. calculation, a counterpoise can be fitted to the other weighpan to exactly balance the added weight of the stone support when it is immersed in the water. This can be made up from a slightly longer piece of similar wire, which can be progressively cut back in length until the beam is in balance. An alternative, and perhaps quicker method, is to add counterpoise weights to the second weighpan.

COMPARATIVE VALUE GUIDE
The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

The four components required for the hydrostatic weighing method can be seen in *Figure 7.2*. These can be obtained from the Gem Instruments Corporation (GIA) and consist of a beaker, a beaker support, a stone support (long wire) and a counterpoise (short wire). ($9.50).

A top-pan type balance specially designed for the measurement of the specific gravity of precious metals and gemstones is the Marumo Model

Figure 7.2
A kit of accessories for the determination of specific gravity by hydrostatic weighing (Gem Instruments Corporation)



PC-50. This is marketed by the Gemmological Association of All Japan (GAAJ). The balance is fitted with a platform which can be swung directly over the weighing pan to support a wire specimen basket.

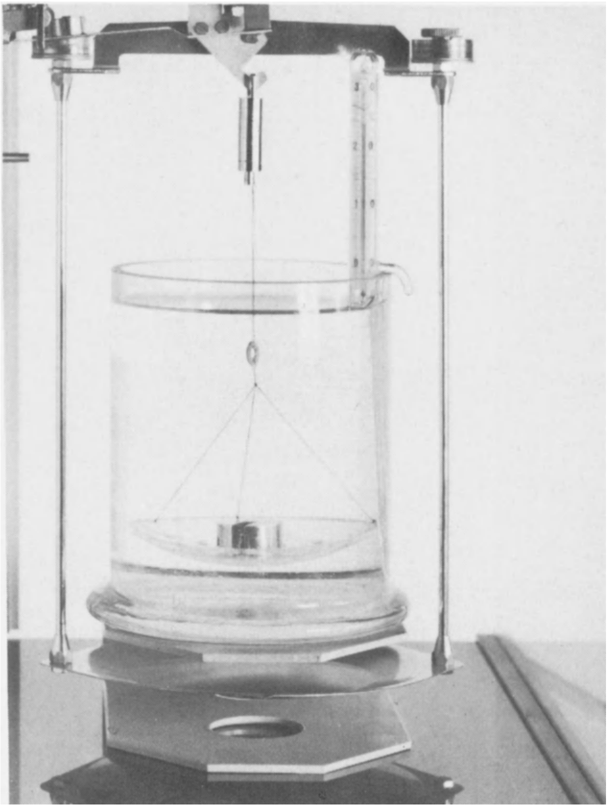
The balance range is 50 carats in 10 carat steps. The balance indicator is calibrated in 0.1 carat graduations. Magnetic damping is provided for fast weighing and the taring adjustment has a range of 2 carats. ($253).

A hydrostatic weighing outfit, comprising a pan bridge, a beaker, a perforated pan (adjusted to 10 grams ± 1 milligram in distilled water at 20°C) and a thermometer (*Figure 7.3*) is available for use with Sauter Analytical balances. Similar sets of accessories are available from Sartorius ($172), Kern/Krüss ($59) and Mettler for their analytical balances.

While it should be remembered that, by definition, specific gravity measurements are related to water at 4° C (when it has a S.G. of exactly 1.0), and in theory the necessary correction should be applied when making tests at room temperatures, this correction only affects the third decimal place in the result and can be disregarded for normal gemmological work.

Of more importance are the possible errors introduced by air bubbles adhering to the gemstone and by the surface tension of the water, which

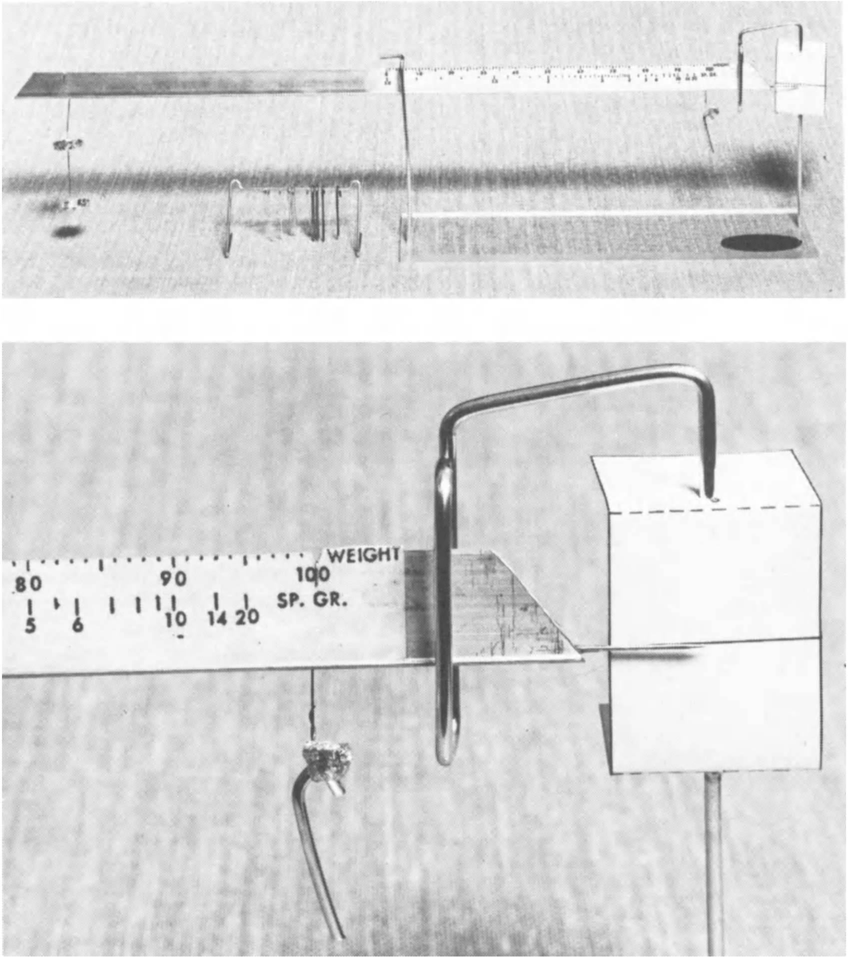
Figure 7.3
View of the beaker pan and thermometer standing on a pan bridge in a Sauter analytical balance (Sauter)



causes a frictionlike drag on the wire stone support as it moves in the water. Bubbles can be removed from the stone by thoroughly wetting it before immersion and then carefully removing any residual bubbles on it, or the wire, by means of a fine paint brush. The use of distilled water, or purified water, will prevent bubbles being formed from air contained in the water. Surface tension effects can be reduced by mixing a drop of detergent with the water in the beaker. Alternatively, the water in the beaker can be replaced by a liquid having a lower surface tension, such as toluene or benzene, and the resulting S.G. determination multiplied by the S.G. of the chosen liquid. As the S.G.'s of toluene (0.87) and benzene (0.88) are much more sensitive to temperature than is water, it is important in this case to make corrections for temperature when this differs from 15 degrees centigrade (i.e. the temperature at which their S.G.s are quoted).

An unusual S.G. balance is illustrated in *Figure 7.4*. This is designed and supplied by Hanneman Lapidary Specialties, and is available in either kit or assembled form. ($10 or $40). The balance enables direct S.G. measurements to be made without the need for calculations, and consists of a long light-weight aluminium beam which is suspended from its centre by a thread.

Figure 7.4
A direct-reading specific gravity balance. Two gemstone weighpans are provided (top left) for in-air and in-water weighings. The counterweight slide (bottom centre) is set to 100 for the in-air weighing, and is loaded (by means of hooked weights) to achieve equilibrium. The gemstone is then transferred to the lower weighpan for the in-water weighing, and the counterweight moved down the scale to restore equilibrium, its new position on the scale indicating the stone's S.G. (Hanneman)



The gemstone to be checked is first weighed in air in the upper of two pans suspended from one end of the beam, and the beam is balanced by adding weights to a 'hanger'. The weighing is then repeated with the gemstone immersed in water in the lower pan, and the beam is brought back into balance by sliding the weight hanger towards the beam's fulcrum. The S.G. of the gemstone can then be read directly from the calibrated scale at the weight hanger suspension point.

HEAVY LIQUID METHOD

This method[1], although less precise than the hydrostatic method, has the advantage that there is no size limitation. In its simplest form it consists of three or four liquids having specific gravities between 2.65 and 4.15. The gemstone under test is immersed in each liquid in turn, and its specific gravity lies between that of the liquid in which it just sinks, and that in which it just floats. The principle in use here is again that of Archimedes, and if the gemstone had, by chance, exactly the same specific gravity as the liquid in which it was immersed, it would experience an upwards force exactly equal to its own weight. As this condition would only be met when it was totally immersed, it would float freely somewhere within the liquid. At this point it should be mentioned that the heavy liquid method of determining specific gravity should not be used for testing porous stones such as opal and turquoise, or stones which have obvious surface cracks and flaws.

In practice, the following four heavy liquids are used:

Monobromonaphthalene ($C_{10}H_7Br$) – S.G. = 1.49
Bromoform ($CHBr_3$) – S.G. = 2.89
Methylene Iodide (CH_2I_2) – S.G. = 3.32
Clerici's Solution* (thallium malonate and thallium formate in water) – S.G. = 4.15

*Care must be taken with this liquid as it is poisonous and corrosive.

For convenience, bromoform and methylene iodide can be diluted with monobromonaphthalene, and Clerici's solution can be diluted with distilled water, to produce liquids having S.G.'s equal to those of the important gemstones. Rapid and more accurate determinations can then be obtained by, for instance, seeing if a suspect tourmaline suspends freely within a liquid adjusted to 3.05. Even if a stone partially floats in a liquid, some idea of its S.G. relative to that of the liquid can be obtained by estimating what fraction of the stone is beneath the surface, and multiplying this by the S.G. of the liquid. If a stone sinks in the test liquid, its rate of sinking will also provide information on how much denser it is than the liquid.

Safety precautions

The following note on safety, published in the April 1979 issue of the Journal of Gemmology, contains advice from the Health and Safety Executive of the Department of Health and Social Security on the use of gemmological test liquids.

> *Care should be taken when using ethylene dibromide* (a suspect carcinogenic liquid sometimes used for S.G. determinations and in hydrostatic weighing), *or any other heavy liquids used in gemmology, to avoid skin contact or inhalation of vapour. On no account should any of*

the liquids used by gemmologists for gem testing be swallowed. In case *of contact with the skin, liquid should be washed off; if in the* eyes, *they should be well flushed out with running water; if swallowed, vomiting should be attempted and medical assistance obtained.*

As with certain other volatile liquids, it is also advisable to avoid smoking when using heavy liquids.

SPECIFIC GRAVITY INDICATORS

The following is a suggested range of test liquids, some of which are prepared by diluting them until a gemstone of the desired S.G. (used as an indicator) is just suspended mid-way in the liquid (or is rising or falling slowly).

1. Monobromonaphthalene – 1.49
2. Bromoform diluted with Monobromonaphthalene to 2.65 (indicator quartz).
3. Undiluted Bromoform – 2.89
4. Methylene Iodide diluted with Monobromonaphthalene to 3.05 (indicator tourmaline).
5. Undiluted methylene iodide – 3.32.
6. Clerici's solution diluted with distilled water to 3.52 (indicator diamond).
7. Clerici's solution diluted with distilled water to 4.00 (indicator synthetic corundum).

[*Note:* An additional 'heavy' liquid, as suggested by Webster, can be made up as required when testing for amber and some of its simulants. This consists of a solution made from ten level teaspoons of common salt dissolved in a tumbler of water. The resulting solution has a sufficiently high S.G. to cause amber (1.08) to float and the various plastic and Bakelite simulants to sink (copal resins and polystyrene cannot, unfortunately be separated from amber by this test)]

As it is possible that the diluted solutions may slowly become more dense due to evaporation, it is good practice to leave a small piece of the indicator mineral in the liquid to serve as a permanent verification of the state of the S.G. of the liquid.

As an alternative to using small pieces of gemstones as indicators when adjusting the specific gravity of test liquids, a box of glass specific gravity indicators can be purchased for this purpose (*Figure* 7.5). The set of indicators, which covers the majority of important gemstones, comprises twenty-one glass discs, each disc being engraved with its S.G. value. Rayner/Gemmological Instruments Ltd. ($67.).

A boxed set of five heavy liquids (S.G. 2.65, 2.71, 2.89, 3.05 and 3.32) is available from Krüss (*Figure* 7.6). The set includes two bottles of adjusting liquids to maintain correct S.G. ($86). A similar set is obtainable from Gem Instruments Corporation. ($44).

Figure 7.5
A box of twenty one glass specific gravity indicators ranging from 2.28 to 4.0. The indicators have their S.G. values indelibly fused into them and these can be easily read when immersed (Rayner/Gemmological Instruments Ltd)

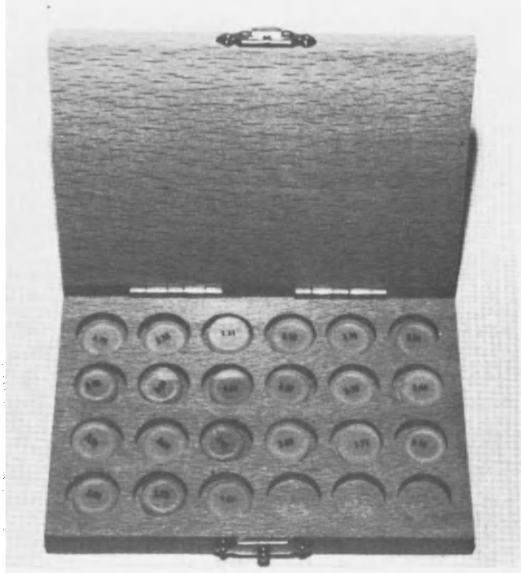
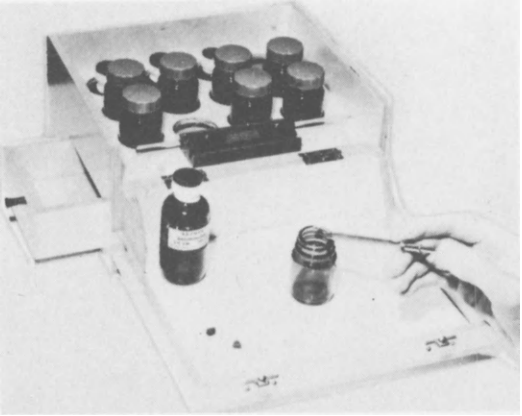


Figure 7.6
A set of five heavy liquids with two bottles of adjusting liquids (Krüss)

Figure 7.7
A boxed set of heavy liquids (Rayner/Gemmological Instruments Ltd)



Gemmological Instruments Ltd., also supply a specific gravity testing set (*Figure 7.7*). This comprises a portable case containing bottles of Clerici's solution, methylene iodide, bromoform and monobromonaphthalene, together with a further eight glass screw-lid pots in which the user can blend mixtures of the appropriate S.G. ($184). Individual heavy liquids can be purchased separately, and a more compact gemmology S.G. kit can be supplied with made up liquids of 2.65, 2.89, 3.05 and 3.32, each containing the appropriate indicator (three bottles of monobromonaphthalene, bromoform and methylene iodide are also provided for topping-up). ($228). Heavy liquids can be purchased in bulk (250 ml) quantities from BDH Chemicals Ltd.

When testing a stone in the heavy liquids it is necessary to use a pair of tweezers, both to drop the stone in and to retrieve it. It is therefore important, to avoid contaminating the liquids, to clean thoroughly both the stone and the tweezers between each individual test.

If methylene iodide is left exposed to strong daylight it will darken in colour owing to the liberation of iodine within the solution. If a few pieces of copper wire or foil are added to the solution, these will combine with the free iodine and lighten the colour of the liquid.

Bromoform also darkens when exposed to daylight, in this case the discoloration is caused by the liberation of bromine. The liquid can be lightened by adding a small quantity of mercury to it and shaking it vigorously. the mercury will absorb the bromine and can then be separated from the bromoform by decanting the liquid.

Warning – The vapour given off by mercury is highly toxic.

SPECIFIC GRAVITY BOTTLE

A much more precise method of determining the specific gravity of a gemstone, using heavy liquids, is first to determine the approximate S.G. of the stone by the previous method, and then to blend a separate heavy liquid mixture to this approximate S.G. figure.

The gemstone under test is then inserted in the heavy liquid, and the S.G. of the liquid is carefully adjusted until the gemstone under test becomes freely suspended. The exact S.G. of this blended liquid (and thus that of the stone) can then be found by the use of a Specific Gravity bottle (*Figure 7.8*). This consists of a small glass bottle having a ground glass stopper through which runs a capillary channel. The bottle is usually calibrated in terms of its internal volume at 20°C (the specified temperature of its contents).

Figure 7.8
A 'Density Bottle' for the determination of specific gravity (Baird and Tatlock)

If the flask is first weighed empty, and then weighed again when filled with the heavy liquid (at 20°C) whose specific gravity is to be determined, the difference in these two readings will give the weight of the heavy liquid. If this weight is then divided by the internal volume of the bottle in millilitres (cubic centimetres) this will give the specific gravity of the liquid and of the gemstone under test.

Flasks, called 'Density Bottles' are available from Baird and Tatlock, and Wood Brothers Glass Co. Ltd, in 10, 25, 50 and 100 millilitre (cubic centimetre) sizes. The bottles are manufactured to conform to British Standard Specification B.S.733:1952.

Reference

1. Mitchell, K. 'Anderson on heavy liquids', *Journal of Gemmology* (1980).

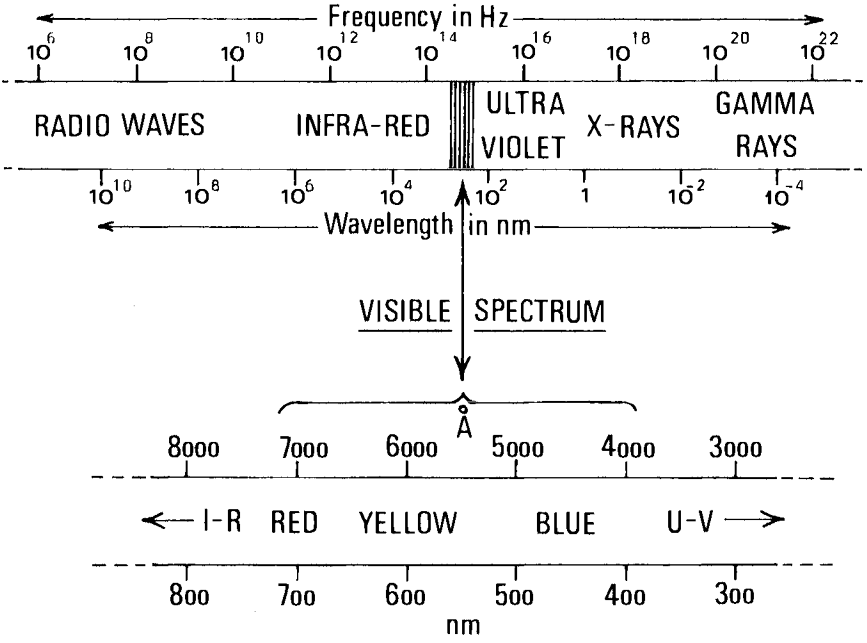
8 Spectra

Absorption and emission spectra. The prism spectroscope. The diffraction grating spectroscope. The reversion spectroscope. Use of the spectroscope.

In Chapter 1 under 'Absorption and emission spectra' a brief explanation was given of the selective absorption of light in a gemstone due to the transition elements and the Rare Earths, and in Chapter 4 we discussed the cause of colour in allochromatic and idiochromatic gemstones. We are now going to look in detail at the way in which selective absorption of wavelengths and bands of wavelengths can be used diagnostically in the identification of gemstones.

The spectrum which most concerns us in gemmological work is the visible one to which our eyes respond. Visible light rays are in fact waves of electro-magnetic radiation, similar to radio waves, but of a much higher frequency. The position and extent of the visible spectrum within the broad electromagnetic spectrum is shown in *Figure 8.1*. As can be seen from this

Figure 8.1
The composition of the electromagnetic spectrum showing the position and relative span of the visible section



figure, our eyes are capable of detecting only a very small segment of the total energy spectrum. This biological 'specialisation' in our viewing acuity is probably the result of evolutionary development, as the ability to see a broader range of frequencies extending from, say, radio waves to X-rays, would result in a very confused perception of our surroundings.

It was Isaac Newton who first demonstrated that white light was composed of a continuous spectrum of colours from violet at one end to red at the other. His equipment which consisted of a circular aperture to admit a beam of daylight into a darkened room and a glass prism to disperse this light into its component colours, resulted in the overlapping of adjacent colours and produced only a poorly defined spectrum. It was nearly two centuries later that a Bavarian optician and scientist named Fraunhofer, using a finer aperture to admit the light, together with a viewing telescope, refined this experiment and first demonstrated that the white light radiated by the sun had in its spectrum a series of black absorption lines. These lines, which are called Fraunhofer lines, were later found by the German physicist Kirchhoff[1] to be due mainly to the absorption of certain characteristic wavelengths by the vapour of various elements in the chromosphere surrounding the sun (see *Table 8.1*). In 1861, Kirchhoff, while working with Bunsen on the investigation of spectra, was able to discover two new metals caesium and rubidium.

The Fraunhofer lines, which could theoretically be used as calibration references for the instruments which are about to be described, are mainly used as a convenient source of fine lines on which these instruments can be adjusted for optimum resolution.

Table 8.1

Fraunhofer line	*Wavelength in nm (X 10 for Å)*	*Element*	
A	762.8 (deep red)	Oxygen	in the earth's atmosphere
B	686.7 (red)	Oxygen	
C	656.3 (orange)	Hydrogen	
D_1	589.6	Sodium	
D_2	589.0 (yellow)	Sodium	
E	527.0 (green)	Iron	
b_1	518.4	Magnesium	
b_2	517.3	Magnesium	
b_3	516.9	Iron	
b_4	516.7	Magnesium	
F	486.1 (blue green)	Hydrogen	
G	430.8 (blue)	Calcium	
H	396.8 (violet)	Calcium	
K	395.3 (deep violet)	Calcium	

Note: The twin sodium lines D_1, D_2 (with a mean wavelength of 589.3 nm) are used as the standard source for the measurement of refractive indices in gemstones. Dispersion is measured as the difference in R.I. at the B and G wavelengths of 686.7 nm and 430.8 nm respectively.

THE PRISM SPECTROSCOPE

Following the early experiments by Newton and then Fraunhofer and Kirchhoff, it was not surprising that the first composite instruments designed for the inspection of spectra all used prisms. These early 'spectroscopes' comprised a small aperture, or slit, to admit the light, a converging lens, a prism and a viewing telescope. The most important refinement here was the collimation of the incident light. This was produced by placing the aperture in the focal plane of the converging lens, thus ensuring that only parallel light rays entered the prism. This resulted in a 'pure' spectrum (i.e. one in which there was no overlap, or contamination, between the component colours).

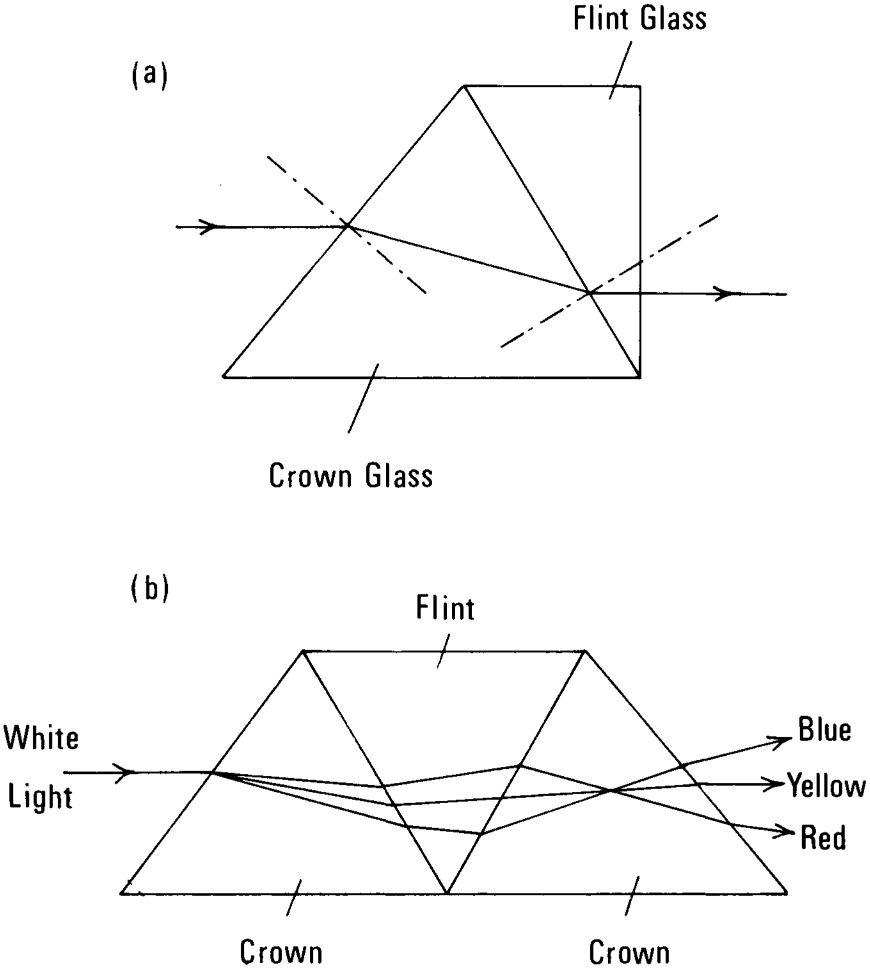
It was soon realised that the angle of dispersion obtained with a single prism was too small to spread the spectrum sufficiently for a detailed examination. If the angle of dispersion was increased by using more than one prism in 'series' the angle of deviation between the incident light and the emerging spectrum soon became unacceptably large. To achieve a reasonably compact instrument with a usable angle of dispersion, it would be necessary to use a multiple prism with zero deviation between the incident light and the centre line of the emerging spectrum.

In 1860, the Italian professor Amici introduced a prism in which two glasses of differing R.I.'s gave dispersion with zero deviation. The main section of this double prism is made of crown glass, and produces the normal dispersion and deviation in the emerging rays. A second smaller prism of flint glass (with a higher refractive index than the crown glass) is cemented to the output face of the first. The flint prism corrects the deviation of the crown glass prism and brings the rays back in line with the incident ray. The angle of the two prisms is chosen so that one of the rays in the emerging spectrum, usually the 'sodium' ray (at 589.3 nm), experiences no deviation from the incident ray (i.e. it is in line, see *Figure 8.2a*).

While this results in an in-line 'Direct-Vision' spectroscope, it does not improve the limited angle of dispersion. However if several of these compound Amici prisms are now placed in series, the angle of dispersion can be increased while maintaining the in-line direct-vision format. When using two Amici prisms in series, the flint glass sections are arranged to be adjacent, and in practice these are combined into a single component to avoid the expense of making two separate prisms and cementing them together (*Figure 8.2b*). Because this combination results in three components (crown glass, flint glass, crown glass) it is regarded as a three-prism unit, and spectroscopes generally use either a three-prism or a five-prism combination.

The construction of a modern direct-vision spectroscope using three prisms is shown in *Figure 8.3*. One of the important components of the spectroscope is the aperture or slit through which the light to be analysed passes. The spectrum produced by the optics of the instrument is in fact a series of images of this slit, one for each resolved section of the spectrum. If the slit is wide, the images will overlap (as they did in Newton's experiment) and the resulting spectrum will not be pure. For this reason,

Figure 8.2
An Amici double prism (a) showing zero deviation. A compound three-prism Amici unit (b) arranged to give zero dispersion of the yellow ray in the emerging spectrum



most spectroscopes are made with an adjustable slit which can be set for a resolution which is relevant to the spectrum being analysed. The setting of the slit width is usually a compromise between obtaining the maximum definition for fine lines, and letting enough light in to produce a visible spectrum. When initially setting the slit and focusing the eyepiece, the spectroscope can be pointed at daylight and the adjustments made for best resolution of the Fraunhofer lines. Alternatively, the spectral lines in the light from a sodium or a fluorescent lamp can be used.

As mentioned earlier, another condition for the production of a pure spectrum is that the light rays falling on the first prism in the series are parallel. This condition is met by inserting a converging lens between the

Figure 8.3
Construction of a three-prism direct-vision spectroscope with wavelength scale

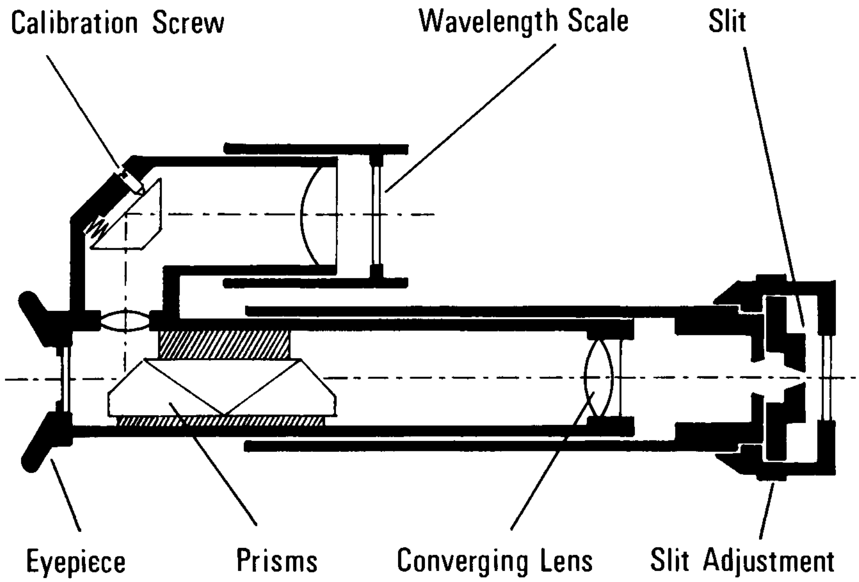
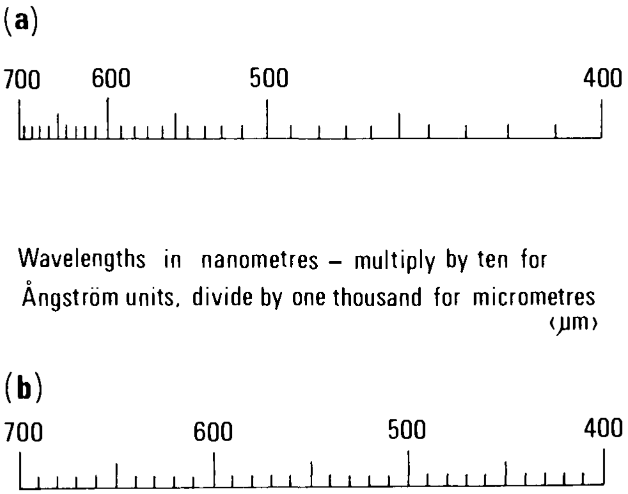


Figure 8.4
The wavelength scale of the prism spectroscope (a) is non-linear, being cramped at the red end and spread out at the violet end. The linear wavelength scale of the diffraction grating spectroscope is shown at (b)



Wavelengths in nanometres – multiply by ten for Ångström units, divide by one thousand for micrometres ‹μm› slit and the prism, and positioning this lens so that its focal plane is coincident with the slit.

An added refinement to the spectroscope is the provision of a calibrated wavelength scale, which, by means of a separate light source and suitable ancillary optics, is superimposed on the image of the spectrum. A calibrating screw is generally provided which enables the scale to be moved relative to the spectrum. This adjustment is usually made when viewing a sodium source so that the 589.3 nm (5893 Å) point on the scale can be set to coincide with the sodium absorption line. In some instruments a calibrated knob moves the spectrum relative to a fixed cursor, the wavelength reading being computed from the control knob reading.

The wavelengths in the spectrum produced by a prism-type instrument are not linearly spaced out, but, due to dispersion, are bunched at the red end and spread out at the blue/violet end (*Figure 8.4a*). This makes it more difficult to resolve closely spaced lines at the red end of the spectrum, and, if the measurement of wavelength is important, makes the provision of a superimposed wavelength scale essential.

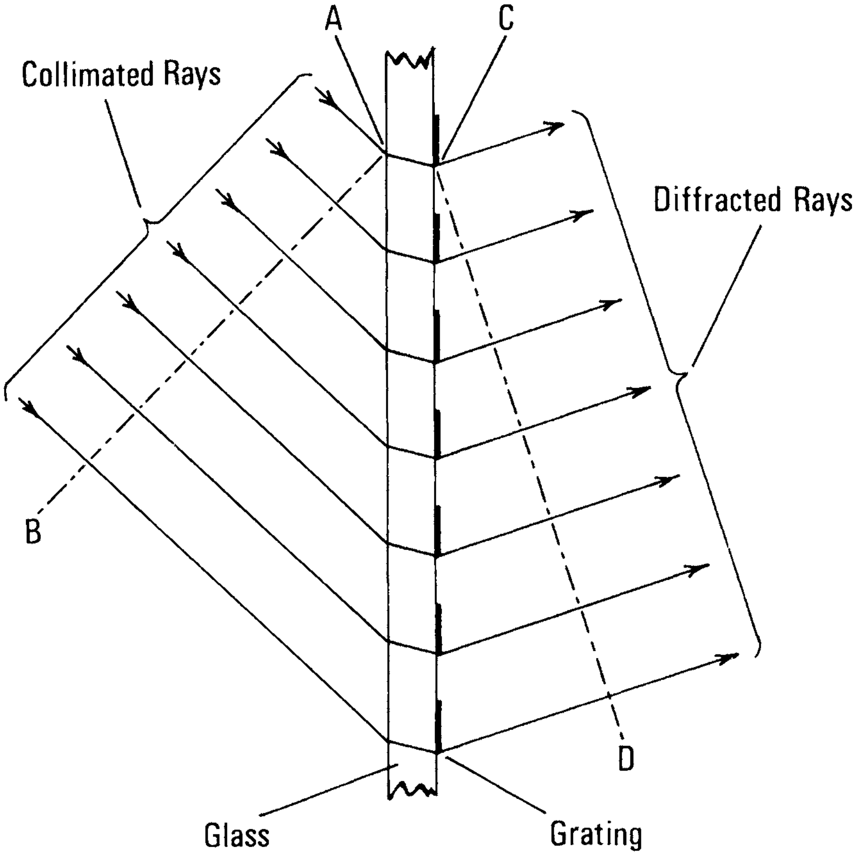
THE DIFFRACTION GRATING SPECTROSCOPE

This instrument, as its name implies, uses a diffraction grating to separate out the light into its spectral components. The grating usually consists of a plate of glass on which is printed or scribed a series of equi-distant parallel lines. The pitch of the lines is in the order of 15 000–30 000 per inch, and these are usually printed on the glass photographically, being optically reduced from a much larger master negative.

While the diffraction grating spectroscope may appear to be a much simpler instrument than its prism counterpart, the optical theory behind its operation is quite complex. The following explanation, without the necessary introductory ground work in wave theory, must of necessity be a simplification.

The production of a diffraction grating spectrum is effected by the twin phenomena of 'diffraction', which is the bending or fanning out of light rays passing through a narrow aperture, and 'interference', which in this case is caused by the differing path lengths in one set of diffracted rays. *Figure 8.5* shows the progressive increase in the path lengths of parallel light rays falling on a diffraction grating. Rays passing through the plane AB are all in phase in that they have all travelled through the same distance from the plane of collimation. If one set of the emerging rays which have been diffracted by the grating are 'sampled' as they intersect plane CD, it will be seen that each successive ray has travelled an extra distance to reach this point. Light is propagated as an electromagnetic wave motion, and among the rays passing through a particular section of the grating, some will be of a wavelength (or colour) where they are 'in-phase' and re-inforce each other, and some will be in anti-phase and will cancel. Thus if a polychromatic collimated light falls on one side of the grating, a spectrum of colours of increasing wavelength will be produced on the

Figure 8.5
Showing the diffraction of light rays as they emerge from a diffraction grating and the resultant differing path lengths which produce a spectrum by mutual interference of the rays



other side as path length differences progressively increase across the grating.

The construction of a typical diffraction grating spectroscope is as follows. The slit lies in the focal plane of a converging lens and acts with it to form a collimator which causes the incident light to fall as parallel rays normal to the plane of the grating. Corresponding to each wavelength in the incident light there is produced a series of diffracted beams, the main one being focused and displayed by means of the viewing telescope.

The resulting spectrum is not so pure or bright as that obtained with a prism spectrometer, as multiple spectra are also produced on either side of the main one and tend to dilute it. The spectrum produced by the diffraction grating spectrometer does however have an advantage over the prism type in that the wavelengths are evenly spaced across the width of the spectrum (*Figure 8.4b*).

While the diffraction grating described uses transmitted light through a grating, spectra can also be produced in the reflected mode by engraving the lines on the surface of a glass plate with a diamond scriber. The interference effect on the collimated incident light is produced in this case by the different path lengths created by the depth of the engraved lines. This method produces, in a more controlled fashion, the play of colour caused by surface structures in some gemstones.

The non-destructive testing of a gemstone by means of its absorption spectrum represents a small part of the total science of spectroscopy. In industry, spectroscopy is used in the measurement of the constituent elements in a sample by vapourising it in an electric arc (or in a laser beam) and inspecting a photographic record of the resulting spectrum. Spectroscopy is also used to inspect the infra-red and ultra-violet regions of the non-visible spectrum and absorption bands here are displayed graphically by means of recording spectrometers which plot the I–R and U–V responses on built-in chart recorders. The latter technique is of particular use in the classification of Type I and Type II diamonds.

Because glass absorbs part of the ultra-violet and infra-red sections of the spectrum, these instruments use lenses of materials which are transparent to these wavelengths. Quartz is transparent to U–V rays and rock salt to infra red. Alternatively, mirrors may be used instead of lenses.

Perhaps the most sophisticated equipment used in this branch of diagnostics is the electron spin resonance spectrometer (ESR) which identifies the presence and quantity of elements in a sample by measuring the microwave energy they absorb at characteristic magnetic field strengths (see Chapter 15).

THE REVERSION SPECTROSCOPE

This version of the standard prism or diffraction grating spectroscope was developed by Professor H. Hartridge, F.R.S, to improve the ease and accuracy with which the wavelength of any particular line or band can be measured. The optics are modified so that two spectra are formed, one above the other, but with the direction of their colours reversed. The spectra are moved across the field of vision by means of a graduated drum, the two spectra travelling in opposite directions. The reading is obtained by setting the line or band in one spectrum against the same line or band in the other, and this can be done with great accuracy.

This method is found to be particularly satisfactory in the case of absorption bands where the outer edges are poorly defined. It also eliminates the difficulty in some instruments of setting an absorption line against a cursor which is not clearly visible, especially in the darker part of the spectrum.

USE OF THE SPECTROSCOPE

While the spectroscope may require more expertise in its use than the refractometer, it comes into its own when identifying either faceted gemstones whose refractive index is too high to be measured on the refractometer, or unpolished gem mineral samples. There are also some occasions when the spectroscope may be the only means of distinguishing a naturally coloured gem from a treated one.

For gemmological work we are primarily interested in using the spectroscope to inspect the way in which the gemstone under test has modified the spectrum of white light passing through the stone or reflected from its surface. As most of the transition elements can be associated with characteristic groups of absorption bands or lines, it is possible with some coloured gemstones to identify the stone positively by means of its absorption spectrum. There are also stones such as zircon and YAG, which may show a 'fine line' spectrum due to the presence of radioactive or 'rare earth' elements. These lines are often so evenly distributed along the spectrum that they have little overall effect on the stone's colour. *Figure 8.5* shows a few of the important gemstone spectra. For a more complete range of spectra, reference should be made to the excellent reproductions in several of the standard gemmological reference books[2].

So far we have considered only the presence of absorption lines or bands in the light spectrum. In some cases it is possible for the energy in the light source, which is illuminating the gemstone under inspection, to stimulate the colouring elements in the stone so that instead of absorbing characteristic wavelengths in the incident light, they emit light at these same wavelengths to produce fluorescent lines.

The most important of the gemstones which show fluorescent emission lines in their spectrum are ruby and red spinel. With both of these stones, the emission lines appear at the red end of the spectrum and are due to the presence of chromium. In order to see the lines more clearly with the spectroscope it is advisable to place a blue filter in front of the light source so that the red/orange end of the spectrum is effectively blocked out. This technique can also be used to advantage when inspecting absorption lines or bands in the blue end of a stone's spectrum.

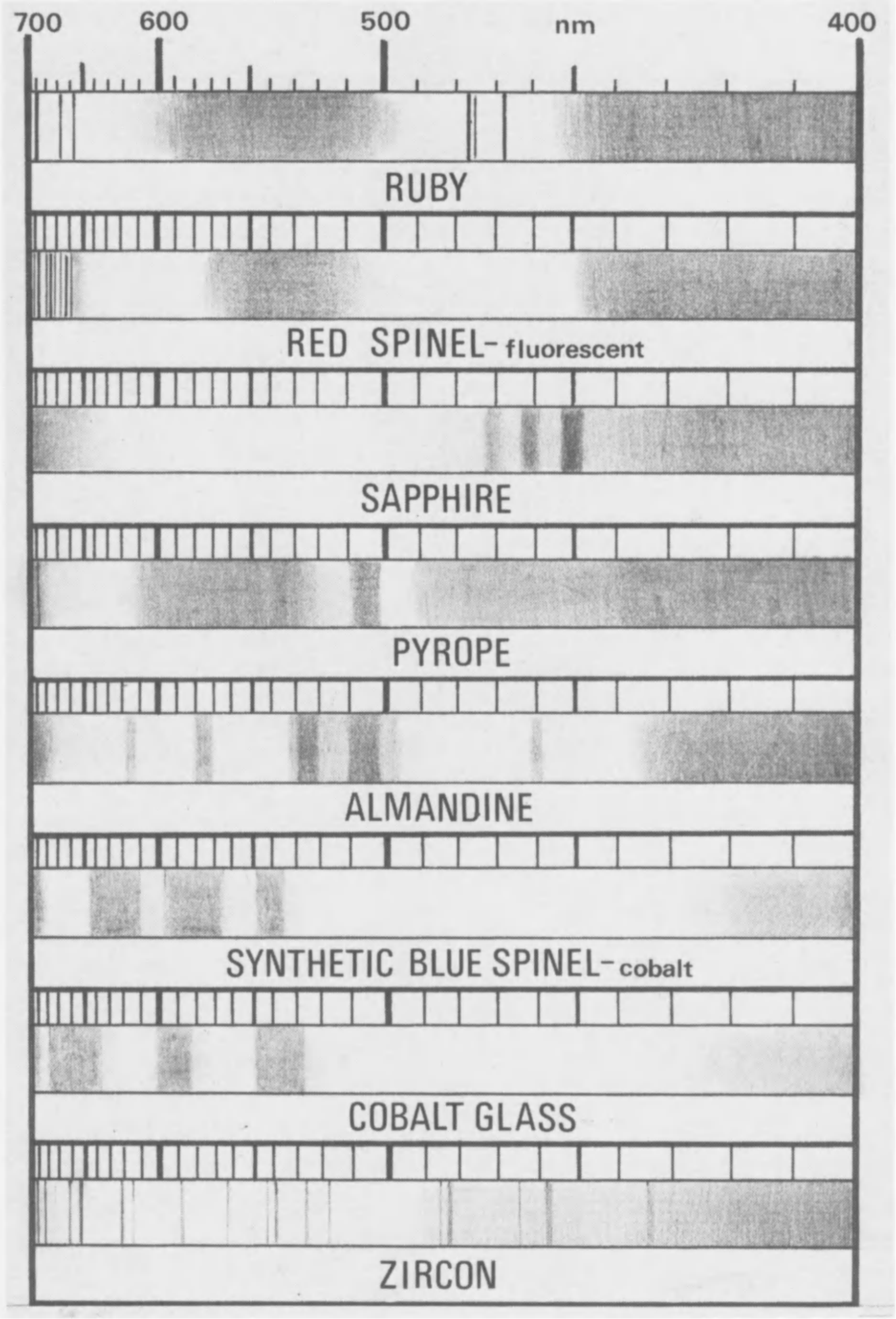
The seven gemstone (and one simulant) spectra shown in *Figure 8.6* are all good examples of absorption lines or bands which are easily recognisable and which can be attributed to specific elements.

The ruby spectrum generally has three distinctive features:

1. A strong doublet in the deep red (at approximately 690 nm, which can be seen in reflected light as a single emission line) followed by two weaker lines centered on 660 nm.
2. A wide absorption band in the yellow/green.
3. Three lines in the blue end of the spectrum.

The presence of the fluorescent chromium doublet in the red, and the three lines in the blue, is confirmatory for ruby, and serves to distinguish it from red spinel.

Figure 8.6
A selection of the more important gemstone spectra



Red spinel, like ruby, is also coloured by chromium, and shows the characteristic emission lines in the deep red. These are usually more numerous than in ruby, and in the bright red chrome-rich types the lines are prominent enough to be described as 'organ pipes'. Unlike ruby, there are no lines in the blue.

The presence of iron in natural blue, green and yellow sapphires is indicated by three broad absorption bands in the blue, although frequently only the band at 450 nm is visible. In synthetic green and yellow sapphires, which are coloured with nickel, these bands are absent. In synthetic blue sapphires produced by the flame-fusion Verneuil process, there is insufficient iron retained in the stone to produce absorption at 450 nm, even when checked on a spectrophotometer.

While both pyrope and almandine contain iron, which in almandine is indicated by three bands in the yellow, green and green/blue, all but the green/blue iron band is obscured in pyrope by the presence of chromium which produces a wide absorption band in the yellow/green.

Synthetic blue spinel is coloured by cobalt. The three broad characteristic cobalt bands in the orange, yellow and green sections of the spectrum serve to distinguish synthetic from natural spinel, which shows a complex broad band structure due to iron. The blue gemstone simulant, cobalt glass, also shows a distinctive cobalt spectrum, but, in this case the centre band is narrower and shifted towards the orange section of the spectrum, while the two outer bands are spaced further apart.

The spectra obtained with zircons are rather variable, ranging from a fine line spectrum caused by uranium in yellow and green zircons, to no lines at all (as often occurs with red zircons). In the majority of zircons which do not show a fine line spectrum, there are usually two lines visible at 653.5 nm and 659.0 nm.

For the recording of spectrum data, sheets of accurately coloured spectra are available from Gemmological Instruments Ltd, each sheet being gummed and perforated into forty strips. Both prism and diffraction grating type spectra are available, and each sheet is printed with the appropriate wavelength scales. ($2 per set of two sheets).

Before putting the spectroscope into use, the slit adjustment should be set to a partially open position, and the instrument focused on either the Fraunhofer lines (by pointing it at a daylight source) or on the lines in a sodium or fluorescent light source. The next move is to illuminate the specimen so that sufficient light can pass through it (or be reflected from it) to form a visible spectrum.

One of the most important pieces of ancillary equipment for use with the spectroscope is, in fact, a source of strong white light. In some composite spectroscope units, this is built in, together with a cooling fan and a heat filter which prevent the specimen from being over-heated. There are several commercial light sources available which use flexible glass fibre light guides to inject the light into the specimen at the most advantageous angle (see Chapter 3). Some hand spectroscopes, such as the Rayner, can be supplied with bench mounts which are fitted with rotatable specimen stands.

Even when the infra-red end of the emission from a light source is removed by means of a heat filter, there is still a considerable amount of energy contained in the light, and it is not advisable to leave a stone exposed to a strong source for too long. Over-exposure can, for example, fade the blue of a zircon, and if a stone contains a stress defect or crack, the light energy may cause this to extend into a fracture.

If a microscope is to hand, it is also possible to use this as a convenient mounting for the spectroscope and as a means of illuminating the gemstone under test. The specimen is placed on the microscope stage, the microscope set for its lowest magnification factor and the eyepiece removed. The source of illumination, the position of the gemstone and the focus of the microscope are adjusted so that the microscope viewing tube is filled evenly with the body colour of the gem. To avoid being temporarily blinded by the strong light emerging from the viewing tube it is advisable, while making this adjustment, to place a piece of ground or opal glass on top of the viewing tube.

If the microscope is fitted with a built-in illuminator, this should be set for light-field work when inspecting a transparent gem, and if an iris is fitted this should be adjusted so that the minimum of light escapes round the edges of the specimen. For opaque gems, an incident light source must be used, and this may also be employed to advantage on transparent or translucent gems.

Having correctly illuminated the gemstone, the spectroscope can now be lowered into the viewing tube and final adjustments made to the slit and focus controls to achieve the clearest spectrum. It should be noted that the focus settings differ slightly from the red to the violet end of the spectrum, and small adjustments may be necessary when inspecting lines at both ends of the spectrum. With strongly dichroic stones it should also be remembered that there will be a difference between the spectrum produced by the ordinary ray and that produced by the extra-ordinary ray. For this reason, such a stone should be rotated so that any change in spectra can be noted before making a diagnosis. Viewing the spectrum with it rotated into a vertical orientation can sometimes help to make faint lines more visible.

In an article in the Gemmological Association of Australia's journal[3], J. H. Oughton makes the following practical suggestions to help the spectroscope user.

1. In order to allow the eyes to become partially dark-adapted so that the fainter lines and bands can be detected, it helps to keep the surrounding level of illumination as low as practical. It is also wise not to stare at a brilliantly lit spectrum for even a short period as this will again reduce the eye's sensitivity.

2. Rather than placing the eye close to the spectroscope eyepiece, try moving the eye back an inch or two. This will restrict the amount of the spectrum that is visible from any particular viewpoint, but this can be turned to advantage by enabling sections of the spectrum to be inspected separately by slowly moving the eye from side to side.

(*Author's Note:* With a prism spectroscope having 13 rather than 7 degrees of dispersion, this situation occurs even with normal viewing.)

3. Try looking for the weak illusive lines or bands by using the more sensitive peripheral area of vision. This can be done by looking slightly away from the part of the spectrum under investigation.

COMPARATIVE VALUE GUIDE
The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

TYPES OF COMMERCIAL SPECTROSCOPE

The remainder of this chapter consists of descriptions of a selection of commercial spectroscopes as used in gemmology. Several commercial light sources,which have been developed for use with both microscopes and spectrocopes, are covered in Chapter 3.

Rayner multi-slit prism spectroscope (Gemmological Instruments Ltd) (*Figure 8.7*)

This is a mechanically robust and compact instrument with a choice of six preset slits of different widths. The slits are covered to prevent the entry of dust, and slit selection is achieved by turning the eyepiece, thus making this adjustment easily accessible when the spectroscope is inserted in the viewing tube of a microscope or in a stand. The eyepiece is fitted in a draw-tube which enables the spectrum to be focused. A supporting ring is available for the spectroscope when it is used in conjunction with a microscope. ($178 plus $11 for support ring).

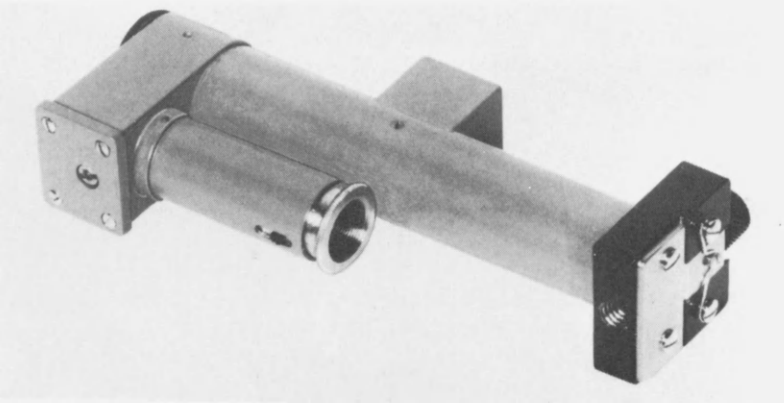
Figure 8.7 shows the spectroscope mounted in a Mitchell stand which is fitted with a rotable platform having a matt black surface, and is intended for use with an incident light. ($28). A 'bull's eye' condenser lens with stand has been designed by Rayners to concentrate light onto the specimen when viewing spectra in the reflected light mode. ($62).

Beck wavelength prism spectroscope 26–3657 (Gemmological Instruments Ltd) (*figure 8.8*)

This instrument is designed for the direct measurement of wavelength, and employs five prisms to produce a dispersion of 10 degrees. The slit is continuously variable and a focusing adjustment is provided. When the instrument is in use an illuminated scale is seen in the field of view. The divisions on this scale represent 10 nm (100 Å), and are numbered.

Figure 8.7
The Rayner Multi-slit prism spectroscope mounted on a Mitchell stand (Gemmological Instruments Ltd)

Figure 8.8
Beck wavelength prism specroscope Type 26-3657 (Gemmological Instruments Ltd)



The illumination of the scale is provided via a tube at the side of the instrument, and depends on an outside source (not provided). The position of the scale relative to the spectrum is adjustable for calibration purposes by means of a screw at the side of the illuminating tube. To facilitate calibration using a sodium source, a calibration point at 589.3 nm is marked on the scale. ($524).

A 'tripod' laboratory type stand is available for use with the Beck spectroscope and enables the instrument to be clamped firmly at the appropriate height and angle. ($37).

Beck diffraction spectroscope 26–3509

The 26–3509 is a simple hand instrument employing a diffraction grating and giving direct vision with a dispersion of 11°. The slit is of a fixed width and is protected by a glass cover plate which also excludes dust. The eyepiece is fitted in a draw-tube which allows the spectrum to be focused. ($32).

Beck reading diffraction spectroscope 26–3590

This spectroscope is designed for taking wavelength readings of spectral lines and bands. It is fitted with an adjustable slit which is set by means of a knurled control. Focusing of the instrument is accomplished by sliding the inner tube, to which the slit is attached, in the outer tube.

When the instrument is in use, a calibrated control at the side is used to move the spectrum across the field of view which is bisected by a fixed cursor line. The line to be measured is moved across the field of view until it coincides with the cursor. The wavelength position of the line is read from the divisions on the calibrated control, whose scale is divided into 100°. The divisions are arbitrary, but can be converted into wavelengths by the use of known spectral lines. A telescope is incorporated to increase the disperson of 34°. ($452).

Beck wavelength reversion spectroscope 26–3806

This is a diffraction grating instrument and uses the reversion principle in which two spectra are moved in opposite directions. The dispersion of the spectroscope is 43 degrees, and at this magnification great accuracy of reading can be obtained. The viewing telescope is mounted on a drum which rotates about the diffraction grating and is actuated by a tangent screw. This screw has an associated micrometer head, whose calibrated control is divided into 100 divisions, each representing 2 Å. The action of the tangent screw is modified by a special device to produce an exact sine relationship to compensate for the radial movement of the telescope, thus maintaining a linear scale calibration. ($1146).

Gem spectroscope unit (Gem Instruments Corp) (*Figure 8.9*)

Employing a Beck wavelength prism spectroscope and a fixed-intensity scale illuminator, this composite unit incorporates a small high-intensity focusable spotlight, which is controlled by a voltage regulator. This permits low-intensity illumination for setting up, as well as high intensity

Figure 8.9
Gem spectroscope unit (Gem Instruments Corporation)

(equivalent to a 1 kW projector) for analysis purposes. The instrument is available for 110 V, 60 Hz and 220–240 V, 50 Hz mains supplies. ($1725).

O.P.L. spectroscope (Orwin Products Ltd.)

This is a low cost hand instrument employing a diffraction grating and a fixed slit preset for optimum resolution. The unit measures 12.5 × 54 mm, and is completely sealed, which makes it useful as a portable instrument. ($37).

Atago spectroscope (*Figure 8.10*)

This is a hand instrument which is used in a mini-lab kit marketed by the Gem Instruments Corporation. The spectroscope is of the prism variety, is focusable, and employs a fixed width slit. ($75).

Portable spectroscope RS10 (Krüss) (*Figure 8.11*)

The RS10 uses a small 7-degree dispersion prism spectroscope and a battery operated illuminator. The central connecting cube contains a stone holder, and the illuminator can be set either at right-angles to the spectroscope for incident illumination, or in line with it for transmitted light. ($236).

Figure 8.10
The Atago prism spectroscope (Gem Instruments Corporation)

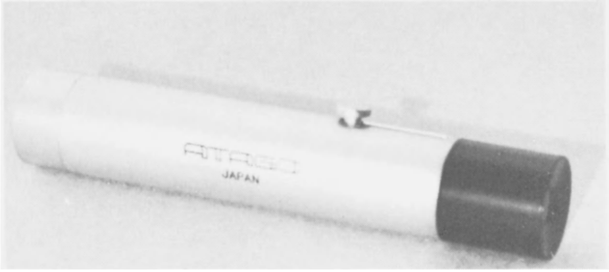


Figure 8.11
The portable spectroscope RS10 can be set for incident illumination (as shown) or for transmitted light (Krüss)

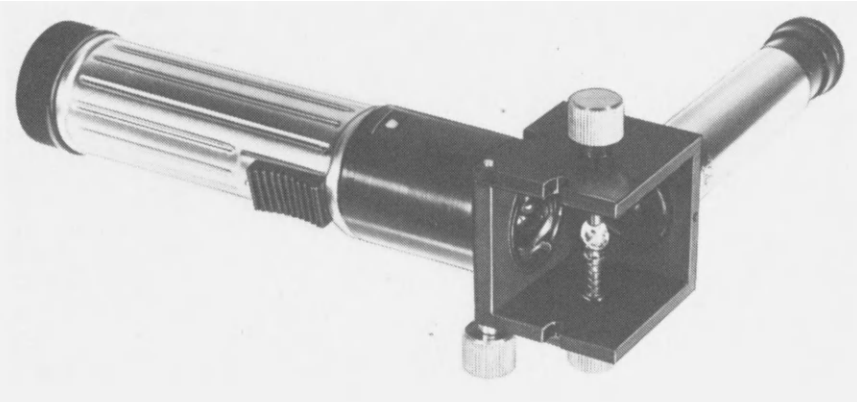
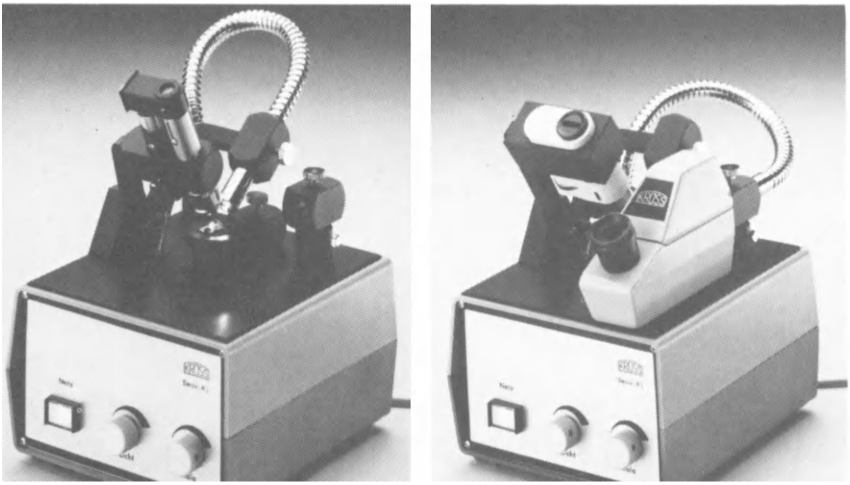


Figure 8.12
(left) The KL7 spectroscope. (right) The KL9 spectroscope with the fibre-optic light guide connected to provide a light source for a refractometer (Krüss)



Gem spectroscope KL7 (Krüss) (*Figure 8.12*)

This is a self-contained unit employing a 55 W 'cold' light source and a 7-degree dispersion prism spectroscope of the wavelength type (covering the range 400 to 700 nm). High-level incident illumination of the specimen is provided by means of a protected fibre-glass light guide which can be pivoted in an arc about the rotatable specimen table. The height of the table can be adjusted to any of three pre-set levels. Like the light guide, the spectroscope can also be rotated in an arc around the specimen. In earlier units, some trouble was experienced with the light guide and spectroscope pivot screws working loose, but this defect has since been corrected. ($900).

Light for the wavelength scale is provided by a separate built-in lamp, and the illumination level of this and the main light source can be independently adjusted by controls on the front panel. An adaptor is provided which enables the light guide to be used as a light source for a refractometer, and as this can be used up to the full intensity level of the 55-watt lamp, it is particularly suitable for refractometers fitted with a 589.3 nm interference filter (see the Krüss ER601 in Chapter 5).

A rotatable filter disc KF10, containing six Schott colour filters, can be mounted on the end of the light guide. ($134). Alternatively, a blue filter can be supplied. ($18). A camera adaptor is also available. ($82).

Gem spectroscope KL9 (Krüss) (*Figure 8.12*)

The KL9 is the same basic unit as the KL7, but is fitted with a 13-degree dispersion wavelength spectroscope covering the range 400 to 800 nm. ($1177).

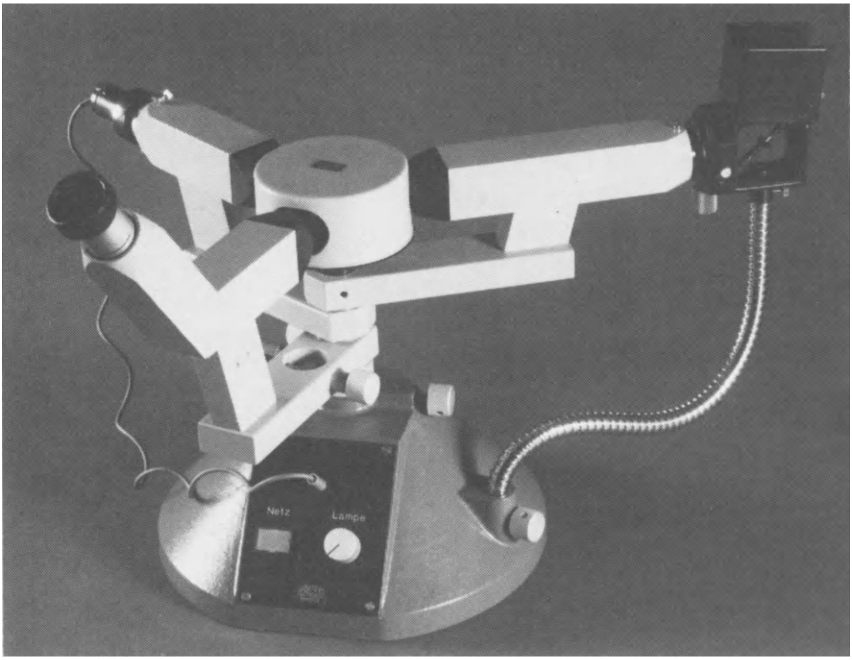
Because of the greater spread of the spectrum, this unit is particularly suited for the inspection of doublets and fine line spectra. The same accessories are available as for the KL7.

Gem table-spectroscope KL1301 (Krüss) (*Figure 8.13*)

This is a modern version of the classical table spectrometer as devised by Kirchhoff and Bunsen in the mid-19th century. The KL1301 consists of a rugged inverted-cone base (which houses the 55-watt cold-light illumination source), a spring-loaded specimen holder (illuminated from the light source via a fibre-optic light guide), a central dispersion table, a wavelength scale projector and a telescope viewer.

The gemstone holder can be modified for either transmitted or reflected illumination. Light rays from the specimen are passed through a collimator and are dispersed into an absorption spectrum by either a prism or a diffraction grating mounted on the central table. A control in the base unit provides adjustment of the light source intensity, and a further control on the side of the telescope support arm enables the spectrum to be moved across the field of view. ($1340).

Figure 8.13
The gem table spectroscope KL1301 (Krüss)



The unit is fitted with a single prism as standard, and covers the range 400 to 700 nm with an effective dispersion equal to 28 mm of scale length. This is adequate for most gem work, and enables the ruby doublet at 694.2 and 692.8 nm to be clearly distinguished as two separate lines.

Accessories include a diffraction grating table (giving the same overall dispersion) ($127), a double prism unit for even greater resolution (effective scale length of 56 mm, equivalent to a dispersion of 40-degrees) ($210, complete with wavelength scale), a goniometer-type specimen table (which can be used to measure the facet angles, refractive index, and, with appropriate filters, the dispersion of gemstones) ($160), and a camera attachment ($43).

Gem table-spectroscope KL1302 (Krüss) (see *Figure 5.20* in Chapter 5)

The KL1302 is a precision version of the KL1301, using a high-resolution diffraction grating, and a micrometer adjustment of the spectrum view. Dispersion is equivalent to a scale length of 48 mm, giving a readout accuracy of 1 nm. A cross-wire telescope eyepiece and two gemstone holders are provided as standard. ($1536). Accessories are as for the KL1301.

Jena hand spectroscope (Jenoptik Jena GmbH/Eickhorst)

This is a direct vision prism instrument with a dispersion of 6° and an externally illuminated wavelength scale with a range of 390–760 nm.

A comparison prism is mounted in front of the adjustable slit and enables a second spectrum from an independently illuminated comparison specimen to be viewed immediately beneath the main one. This is one of the best 6° dispersion prism spectroscopes available. ($315).

Coldlight-spectroscope Modul 5 (Eickhorst/Rubin) *(Figure 8.14)*

This is a composite unit, designed to match other gemmological instruments in a Gemmodul range employing the same design style. The unit employs the Jena hand spectroscope as described above.

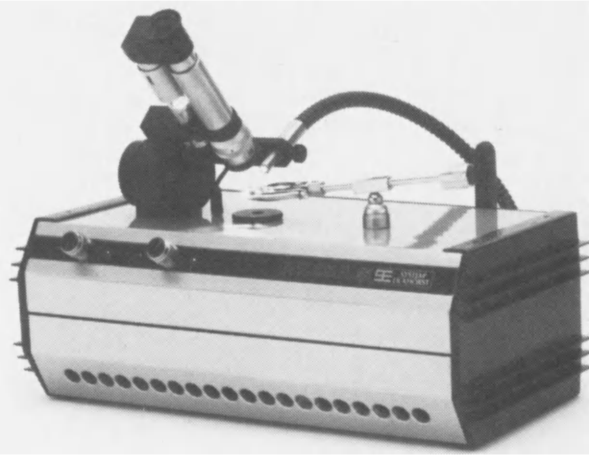


Figure 8.14
The Modul 5 spectroscope with light source and illuminated wavelength scale (Eickhorst)

The built-in light source is a 12 V, 100 W quartz iodide lamp whose light is focused into a glass fibre adaptor. Two glass fibre light guides can be channelled into the adaptor to provide transmitted or incident light for the specimen mount (adjustment is by means of a vertical rod control at the rear of the unit). The tendency in earlier models for the glass fibres at the end of the light guide to fracture has been corrected by better protection and termination.

The intensity of the light source is continuously variable, and the clamp for the incident light guide can be rotated in an arc about the specimen mount, as can the spectroscope. A separate lamp with a variable intensity control is provided to illuminate the wavelength scale. The provision of a cooling fan and a heat filter ensure that the specimen is not over-heated. ($877).

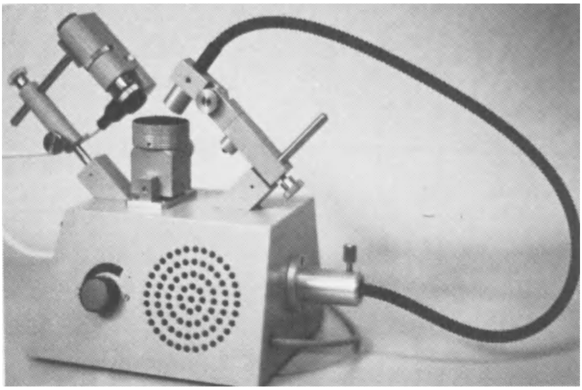


Figure 8.15
The Hans-Günter Schneider spectroscope unit with built-in cold light source and fibre-optic light guide

Wavelength Spectroscope (GAAJ)

This is a composite unit employing a hand spectroscope (with illuminated wavelength scale) mounted on a support arm which permits it to be positioned over a range of angles relative in the specimen. A stoneholder is provided for manipulating the specimen, and the intensity of the light source is adjustable. ($598). The spectroscope which has a dispersion of 10°, can be supplied separately.

Spectroscope unit (Hans-Günter Schneider)

This consists of a mounted prism spectroscope of the wavelength type with adjustable wavelength illumination. ($755).

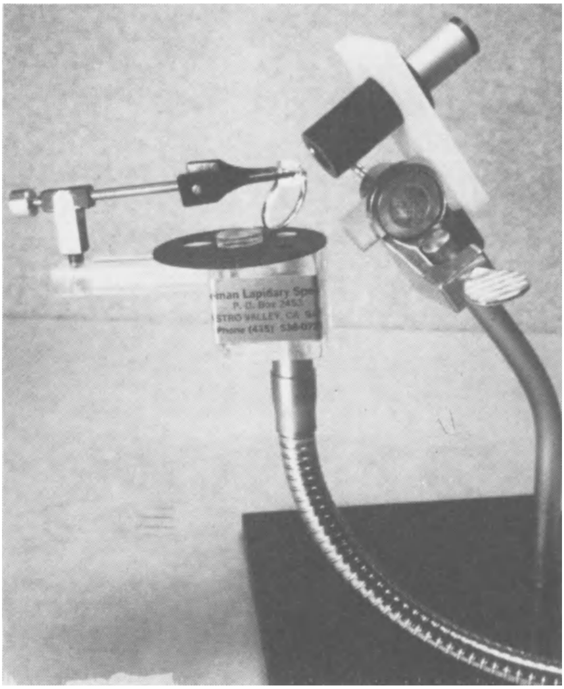
Coldlight spectroscope unit (Hans-Günter Schneider) (*Figure 8.15*)

The Coldlight spectroscope unit is a composite instrument fitted with a prism spectroscope of the wavelength type. It has adjustable wavelength illumination, and a built-in light source for specimen illumination. A fibre-optic light guide is used to channel light from the source to the rotatable specimen table. Both the spectroscope and the light guide are adjustable in position and angle. ($1318).

Mini-cube S-1060 (Hanneman) (*Figure 8.16*)

This consists of a transparent plastic cube, recessed at the bottom to fit either a fibre-glass light guide or the Hanneman penlight as a light source. The top of the cube is fitted with a revolving disc containing apertures of various size to control the light throughput. (Cube with bracket but less stoneholder, $20. Spectroscope stand, $45. Penlight, $2.50).

Figure 8.16
Minicube (fitted with Rayner stone holder) used to direct light into a mounted gemstone (Hanneman)



Gem table spectroscope (Gem Lab)

This is a composite instrument fitted with a 7-degree prism spectroscope (with a wavelength scale) and fibre optic illumination from a quartz halogen lamp. Separate controls provide adjustment of the sample and scale illumination. ($995).

References

1. Kirchhoff-Bunsen, *Spektralanalyse* (1859). Gives the experimental results obtained with the spectroscope designed by Bunsen in which the spectral lines of the elements were observed by colouring a bunsen flame with samples of the elements, deduces the general law connecting the absorption and emission of light, and recognises that each element has a characteristic spectrum.
2. Anderson, B. W., *Gem Testing*, 9th edn, Butterworths (1980).
   Webster, R., *The Gemmologist's Compendium*, 6th edn, NAG Press Ltd (1980)
3. Oughton, J. H., 'Handling notes – The direct vision spectroscope', *The Australian Gemmologist* (February 1976)

Table 8.2

Manufacturers or suppliers (see Appendix A for addresses).	*Prism spectroscope*	*Diffraction grating spectroscope*	*Composite units (stand and light source)*	*Reversion spectroscope*
Atago/Gem Instruments		●		
Ealing Beck	●	●		●
Ealing Beck/ Gemmological Instruments Ltd	●			
Eickhorst	●		●	
Gem Lab	●		●	
Gem Instruments Corp	●	●	●	
GAAJ	●		●	
Orwin Products Ltd		●		
Jena/Eickhorst	●			
Krüss	●		●	
Hans-Günter Schneider			●	
Rayner/ Gemmological Instruments Ltd	●			
Rubin	●		●	

9 Luminescence

Fluorescence and phosphorescence. Cathodoluminescence. Triboluminescence. Crossed filters. LW and SW ultra-violet lamps. X-ray equipment.

When some substances are subjected to energy in the form of electromagnetic radiation (i.e. light, X-rays, etc.) they respond by emitting radiation at a characteristic wavelength. This is the result of the excitation energy causing electrons in the atoms of the substance to move out of their normal atomic orbits to ones of a higher level. When these electrons return to their original orbits, they emit the surplus energy in the form of electromagnetic radiation. This emitted radiation is always of a longer wavelength than that of the original excitation (as stated in Stokes Law).

The orbital movements of the electrons in such a substance occur in a random fashion, and when there is virtually no delay between electrons gaining energy, and then losing it again by emitting light, the phenomenon is called 'fluorescence'.

If, however, there is an observable delay before the electrons give up their surplus energy by emitting light, the phenomenon is called 'phosphorescence'. Both fluorescence and phosphorescence are grouped under the common heading of luminescence. More specifically, luminescence caused by electromagnetic radiation is termed 'photoluminescence' to distinguish it from luminescence caused by other forms of energy such as heat or friction.

In practical terms, if the source of irradiation is switched off, or removed, and the substance ceases to luminesce, this is a fluorescent effect. If, however, the luminescence continues for a noticeable period after the radiation is switched off, this is a phosphorescent ('after-glow') effect.

In research work irradiation of a gemstone (in a vacuum) by means of an electron beam produces a luminescent effect known as 'Cathodoluminescence'. This is described under 'Research laboratory equipment' in Chapter 15. Another type of luminescence called 'Triboluminescence', is caused by the frictional excitation of a substance. It is very occasionally seen in a diamond when this is being polished on a 'scaife' (a cast iron rotating disc impregnated with diamond dust), and causes the diamond to fluoresce blue or red with an intensity that makes it easily visible even in daylight.

For the purpose of gemmology, the fact that the emitted radiation is always of a longer wavelength than that of the applied radiation is of prime importance. It means that visible light is often emitted by a gem mineral when it is irradiated by a source having a much shorter wavelength, such as ultra-violet light or X-rays. With some gemstones (and synthetics), even the short wavelength visible light in the blue/violet end of the spectrum will result in the emission of a longer wavelength red light.

This latter phenomenon was first put to practical use by the British physicist G. G. Stokes in 1852, and was later adapted by B. W. Anderson for the identification of gemstones in the Gem Testing Laboratory of the London Chamber of Commerce. It must be pointed out that the crossed filter method has nothing to do with polarising filters, as might first be thought, but involves the use of colour filters.

The various forms of electromagnetic radiation available to the gemmologist are, in fact, visible light, longwave ultra-violet light, shortwave ultra-violet light and X-rays. Each of these forms of energy has its particular application in the identification of gemstones by means of their luminescent properties[1]. The techniques and equipment associated with each of the four forms of radiation will now be discussed in more detail.

CROSSED FILTERS

This is the simplest of the methods, in that the equipment required is generally to hand, and is not specialised. All that is needed is a strong source of white light, a blue filter and a red filter. These colour filters can be of the simple gelatine variety sandwiched between sheets of glass to protect them from heat (i.e. Wratten filters[2], available from Kodak Ltd), although Mr. B. W. Anderson recommends the use of a filtered solution of copper sulphate in a flask for the blue filter. This has the twin advantage of acting as a condensing lens and a heat filter.

The blue filter is placed between the light source and the gemstone, and the gemstone is viewed through the red filter. If only the blue filtered light is allowed to fall on the gemstone (by suitable shielding), and the stone is seen to glow when viewed through the red filter, it must be fluorescing.

Gemstones which demonstrate their fluorescence most readily under crossed filters are those which owe their coloration to chromium-oxide impurities. Such gemstones are principally ruby and red spinel, both natural and synthetic.

Emerald, pink topaz and the rarer alexandrite also fluoresce red under the crossed filters, although this may be inhibited in emerald and alexandrite by the presence of iron, even in small quantities. For this reason, synthetic emerald fluoresces more strongly than natural stones, as the latter often contain traces of iron. Pyrope and jadeite, which contain both chromium and iron, do not fluoresce at all. Natural black pearls fluoresce with a faint red glow which distinguishes them from those artifically stained with silver nitrate.

COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

LW ULTRA-VIOLET LAMPS

Ultra-violet radiation sources use mercury discharge lamps as these have strong spectral emission lines ranging from yellow to the far ultra-violet. The dominant mercury emission line which is used for longwave ultra-violet work has a wavelength of 366 nm. To avoid the luminescence of a gemstone being masked by the visible emission lines in the mercury lamp's spectrum, a filter is used which blocks out most of the visible light rays.

The filter used for LW ultra-violet lamps is a Wood's glass filter, which contains cobalt and a trace of nickel. One commercial version of this is the Chance Filter OX1 which is available as a 50 × 50 mm glass square from Gemmological Instruments Ltd ($26). The mercury lamp used for LW work is a high-pressure discharge type.

While the commercial lamps which are reviewed in this chapter are relatively low in the intensity of their ultra-violet emission, it is not advisable to look directly at any of them unless special protective glasses or goggles are worn. Among the protective glasses produced by U–V Products Inc, are safety 'contrast control' goggles. ($16). These, because they filter not only the harmful ultra-violet rays but also the visible violet rays, also improve the contrast of the luminescing stone by removing the violet haze passed by the lamp filter.

Types of luminescence

The following notes indicate the type of luminescence to be expected with some of the more important gemstones.

Ruby and red spinel show a spectacular red fluorescence under LW ultra-violet, but surprisingly other chromium bearing minerals such as emerald, pink topaz and alexandrite do not respond so well and are best tested for fluorescence using the crossed filter method. Synthetic emeralds usually show a strong crimson fluorescence.

Green and yellow synthetic spinels, which contain manganese as their colouring element, show a bright green fluorescence. Blue synthetic spinels fluoresce red.

White sapphires generally fluoresce orange, but yellow and white sapphires from Sri Lanka, glow a characteristic apricot yellow which distinguishes them from synthetic yellow corundum. Yellow sapphires from Australia and India do not fluoresce at all. Synthetic orange and yellow sapphires glow a strong red.

Gadolinium gallium garnet (GGG) has a straw coloured fluorescence (see under SW Ultra-violet Lamps and X-ray equipment).

Diamonds in the Cape series (shades from white to yellow) which fluoresce blue under LW ultra-violet illumination, phosphoresce yellow. The eyes need to be dark-adapted to detect this persistent yellow after-glow, but when seen, it is confirmatory for diamond, as there is no other blue fluorescing mineral which exhibits yellow phosphorescence.

Scapolite fluoresces yellow, and this serves to distinguish it from quartz. YAG also glows yellow, unlike strontium titanate which does not fluoresce at all.

Lapis lazuli fluoresces orange, but as this is not a homogeneous mineral but a rock mixture its glow occurs in patches. Kunzite also glows orange or gold (see under X-ray Equipment).

Danburite can be identified by its sky-blue fluorescence, and the majority of the aptly named fluorspar glows a strong green or blue under the LW ultra-violet lamp.

Opal may show a white, bluish, brownish or greenish fluorescence, often with a persistent green phosphorescence. Synthetic opal shows no phosphorescence.

Most zircons fluoresce a characteristic mustard yellow under LW ultra-violet light. Moonstones usually fluoresce blue.

Yellow apatite fluoresces lilac, blue apatite glows violet to sky blue, green apatite glows deep yellow, and violet apatite glows greenish yellow (see under SW Ultra-violet Lamps and X-ray Equipment).

LW ULTRA-VIOLET LAMP UNITS

The following paragraphs describe a selection of commercially available LW ultra-violet lamps.

UVL-56 Blak-Ray lamp (U–V Products Inc)

This is a hand-held lamp incorporating a 6 W lamp with a curved specular reflector and an appropriate filter. Typical output intensity at 366 nm is 800 μW/cm^2 measured at 6 in. from a new filter. ($136).

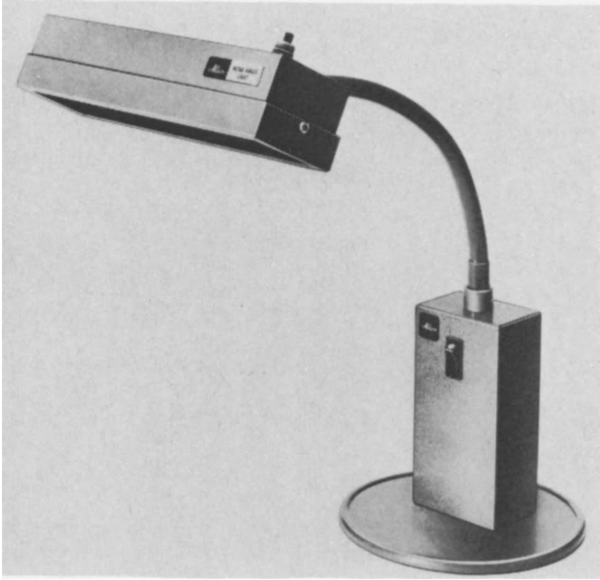
The lamp is for mains operation, but can be converted to battery operation by the addition of a special adaptor. The unit can be clipped to a desk stand.

UVL-21 Blak-Ray lamp (U–V Products Inc)

This is similar in appearance to the multi-band lamp UVSL-25 in *Figure 9.4*. It uses a 4 W lamp with a curved specular reflector. Typical output intensity at 366 nm is 460 μW/cm^2 at 6 in. from a new filter ($90).

Like the UVL-56 it is for mains operation but can be adapted for use from batteries. The unit can be clipped to a desk stand. It can also be used with the CC-10 portable darkroom viewing cabinet (see *Figure 9.5*). ($110).

Figure 9.1
The Allen LW U-V bench light A409 (P. W. Allen & Co.)



U–V bench light A409 (P. W. Allen & Co/Gemmological Instruments Ltd.) (*Figure 9.1*)

This unit uses two miniature 230 mm (9 in.) fluorescent tubes with a special aluminium reflector and a Wood's filter. The average tube life is in excess of 5000 hours. A 'starter' button is provided to initiate the lamp discharge.

The unit is designed for mains operation of 110–115 V or 220–240 V, A.C. ($136 and $126 respectively).

U–V desk lamp A410 (P. W. Allen & Co.) (*Figure 9.2*)

This unit is designed to give the specimens under examination some shielding from room lighting. It incorporates the same lamp assembly as the A409. ($130).

Portable U–V examination lamp A480 (P. W. Allen & Co.) (*Figure 9.3*)

This is a hand-held unit powered from self-contained HP11 batteries. The unit is supplied with a protective carrying case. ($58).

UV analysing lamp AL33 (Krüss)

This is a hand-held battery-operated unit. ($200).

Figure 9.2
The Allen LW U-V bench light A410 partially shields the specimens from ambient light (P. W. Allen & Co.)

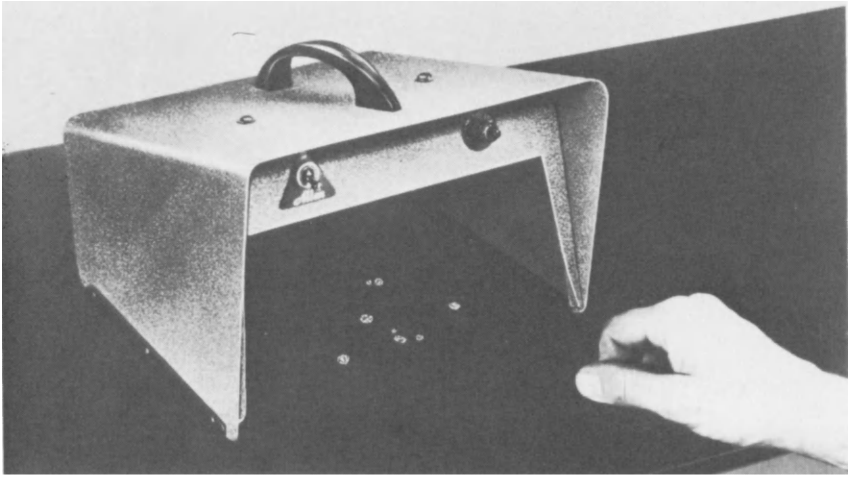
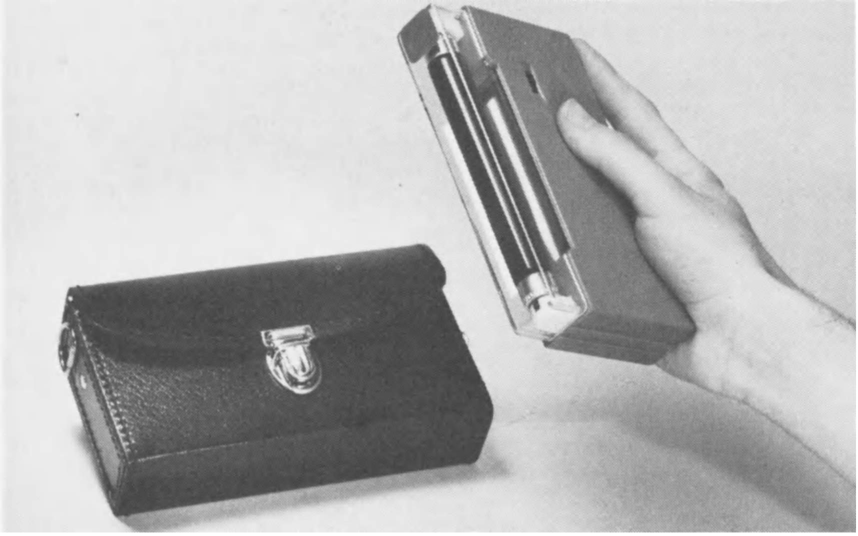


Figure 9.3
The battery-operated portable LW U-V lamp A480 (P. W. Allen & Co.)



Model Q-22 multi-purpose inspection lamp (Spectronics Corp/Orme Scientific)

This is a hand-held visible/LW UV lamp with built-in 2 in. × 4 in. lens. ($230). A heavy duty version, Model Q-22S is also available and is supplied with a pedestal stand. ($250).

SW ULTRA-VIOLET LAMPS

The mercury lamp used for SW ultra-violet work is a low pressure vapour type, using a quartz tube or envelope. the shortwave mercury line at 254 nm is dominant in the emission spectrum of this lamp, and a Chance OX7 filter is used to pass this wavelength while filtering out most of the visible light in the lamp's emission spectrum. This filter is available as a 50 × 50 mm glass square from Gemmological Instruments Ltd. ($47).

It should be noted that shortwave ultra-violet filters deteriorate during use and should be checked for efficiency after about 100 hours of operation. LW and SW lamps also suffer a loss of efficiency during use, and their outputs may fall by up to 20% in the first 100 hours. A U-V intensity meter is manufactured by U-V Products Inc, which permits both the filter and the lamp to be checked. The meter, which is a compact battery-powered unit, is calibrated in microwatts per square centimetre ($\mu W/cm^2$) and has an accuracy of ±15%. One version is available for LW measurements and one for SW. ($590).

While SW ultra-violet light can be useful in assisting in the identification of some stones, LW ultra-violet light is broader in its application and is therefore of more general use. However, another use of SW U-V is in distinguishing synthetic rubies, sapphires, emeralds and alexandrites from natural stones by the latter's poorer transparency to these rays brought about by the presence of iron oxides. A gemstone tester using this principle is described in Chapter 16.

Reaction of gem minerals to SW radiation

The following notes indicate the response of some of the more important gem minerals to SW radiation, where these differ from the response under LW ultra-violet.

Synthetic white sapphires fluoresce a weak deep blue/violet under SW ultra-violet light, but natural white sapphires rarely glow (due to the presence of iron). Synthetic blue sapphires show a strong greenish blue fluorescence (due to titanium) in contrast to natural blue sapphires whose glow is inhibited by the presence of iron.

White synthetic spinels fluoresce a strong blue/white in contrast to their lack of fluorescence under LW ultra-violet rays. Gadolinium gallium garnet (GGG) glows a peach colour (see under X-ray Equipment).

Moonstone shows an orange fluorescence (in contrast to blue under LW ultra-violet). Scapolite tends to fluoresce pink (in contrast to yellow under LW radiation).

Yellow apatite fluoresces lilac/pink, and violet apatite glows pale mauve (see under LW ultra-violet lamps and X-ray Equipment).

COMBINED SW AND LW ULTRA-VIOLET LAMP UNITS

The following paragraphs describe a selection of commercially available ultra-violet units combining SW and LW lamps.

UVGL-25 Mineralight multi-band lamp (U-V Products Ltd/Rubin/Gem Instruments Corp.) (*Figures 9.4, 9.5*)

This unit is fitted with a 4 W LW tube and a 4 W SW tube. Each tube has a separate push-button on/off control. The tubes are fitted with a curved specular reflector, and give typical intensities of 180 μW/cm^2 at 254 nm and 280 μW/cm^2 at 366 nm, measured at 6 in. from a new filter. ($190).

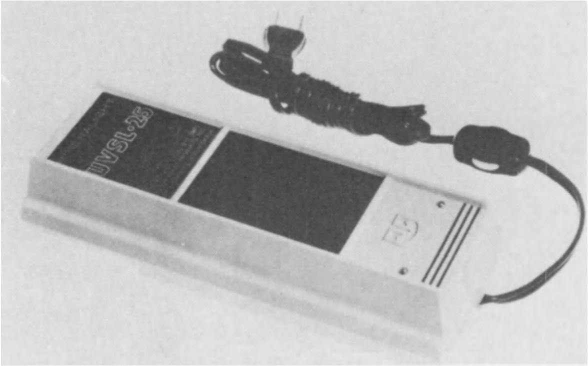


Figure 9.4
The combined LW/SW U-V lamp UVGL–25 (U-V Products Inc.)

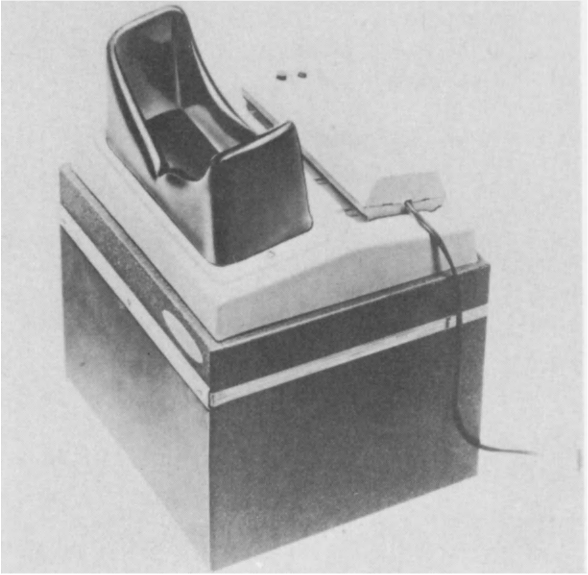


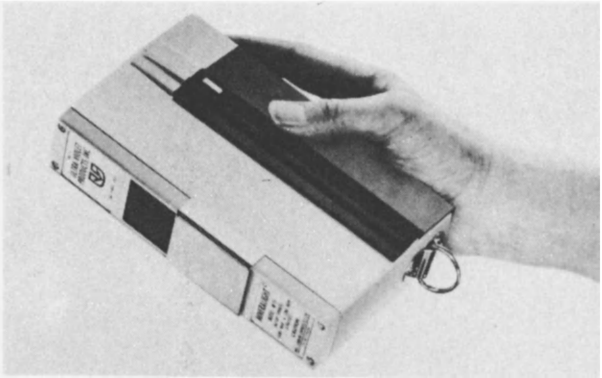
Figure 9.5
Showing the UVGL-25 lamp fitted to the CC-10 darkroom viewing cabinet (U-V Products Inc)

It is designed for mains operation, but can be converted to battery operation by the addition of a special adaptor. The unit can be clipped to a desk stand. It can also be used with the CC-10 portable darkroom viewing cabinet. ($110).

Mineralight G1-14 (U-V Products Inc/Rubin/Gem Instruments Corp.) (*Figure 9.6*)

This is a hand-held battery operated unit incorporating a 4 W lamp with a curved specular reflector. The LW and SW outputs can be used separately or together by means of a wavelength selector. ($312).

Figure 9.6
The G1-14, a hand-held battery LW/SW lamp (U-V Products Inc)



Typical intensity at 254 nm is 180μW/cm^2, and at 366 nm is 190 μW measured at 6 in. from a new filter. The battery gives one hour's operation from a 16-hour charge.

Multispec combined LW/SW unit (GAAJ/Gemmological Instruments Ltd) (*Figure 9.7*)

This is a totally shielded unit, giving the viewer complete protection against ultra-violet radiation and ensuring perfect darkroom conditions. The SW and LW tubes and filters are independent assemblies with their own on/off controls. The unit is for operation from 110 V or 220 V mains, 50/60 Hz. ($282).

U-V lamp UV-AC and Darkroom M6 (Eickhorst) (*Figure 9.8*)

This unit consists of a combined LW and SW U-V lamp fitted to a darkroom cabinet. The cabinet is styled to integrate with the Eickhorst Gemmodul series of units. ($180, plus cabinet $62).

Figure 9.7
The Multiscope combined LW/SW U-V lamp and darkroom cabinet (CAAJ/Gemmological Instruments Ltd)

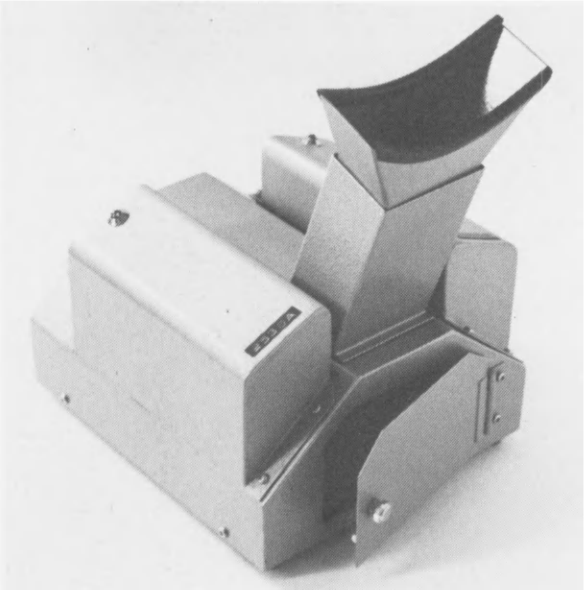
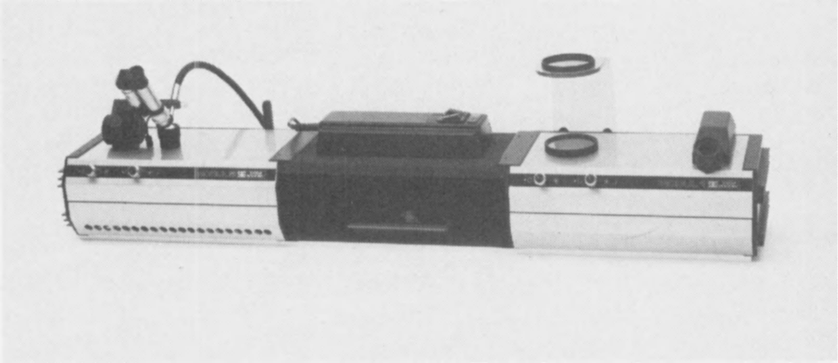


Figure 9.8
The combined LW/SW U-V lamp UV-AC and darkroom cabinet M6 can be seen in the centre of this Gemmodul assembly (Eickhorst)



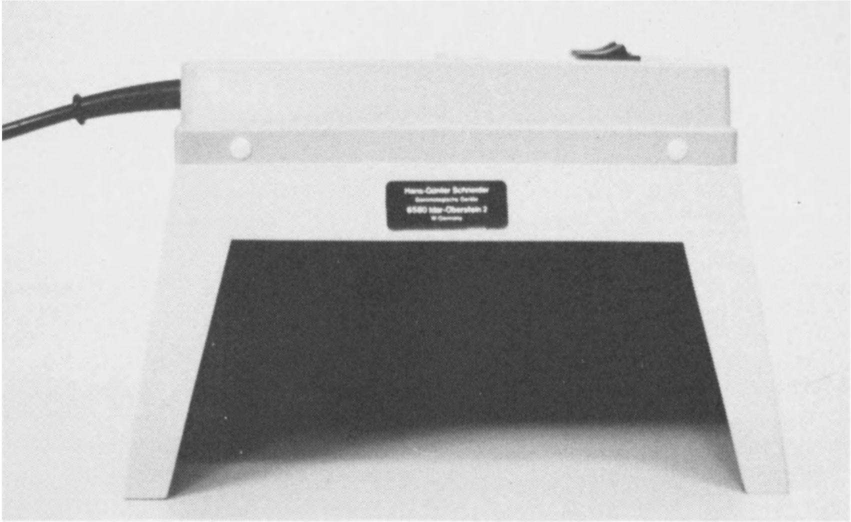
UV-Analysis lamp 204AC (Hans-Günter Schneider) (*Figure* 9.9)

The housing for the combined LW and SW lamp unit 204AC also serves to shield specimens under test from ambient light. ($241).

UV Analysing lamp AL32 (Krüss)

This is a combined LW and SW lamp unit with change-over switch. ($200). A darkroom cabinet DK32 is also available. ($86).

Figure 9.9
This LW/SW U-V unit also shields the specimens from ambient light (Hans-Günter Schneider)



X-RAY EQUIPMENT

X-ray radiation sources are more generally the province of the research laboratory because of the size of the equipment and the necessary precautions against radiation dangers.

While the following notes indicate the effects of X-ray irradiation of certain gem minerals, this type of radiation is of more use in testing stones in terms of their transparency or opacity to X-rays. In this respect, an X-ray source can form a useful means of distinguishing diamond from its simulants. Diamond, because of its very simple atomic and crystalline structure and its low atomic number (6), is transparent to X-rays while all diamond simulants show some degree of opacity. A small X-ray equipment for making this type of test is described at the end of this chapter.

Effects of X-ray irradiation

Almost all diamonds exhibit a chalky blue fluorescence under X-rays, with no phosphorescent after-glow.

Of the synthetics, strontium titanate shows no response. YAG fluoresces yellow and synthetic red corundum glows red (as does natural ruby), but unlike natural ruby shows a phosphorescent after-glow. Synthetic orange and yellow sapphires show a red fluorescence with a phosphorescent after-glow. Synthetic colourless sapphires show no fluorescence, unlike naturals which fluoresce crimson (with no phosphorescence).

Fluospar shows a phosphorescent effect after exposure to X-rays. Kunzite glows a strong orange and the colour of the stone changes temporarily to a bluish green.

Gadolinium gallium garnet (GGG) fluoresces lilac (see under LW and SW ultra-violet lamps), with no phosphorescence.

Yellow apatite fluoresces pinkish white to pinkish yellow, blue apatite shows a dim pinkish straw colour, green apatite glows a yellowish white, and violet apatite fluoresces a very bright greenish yellow and exhibits a persistent phosphorescence (see under LW and SW ultra-violet lamps).

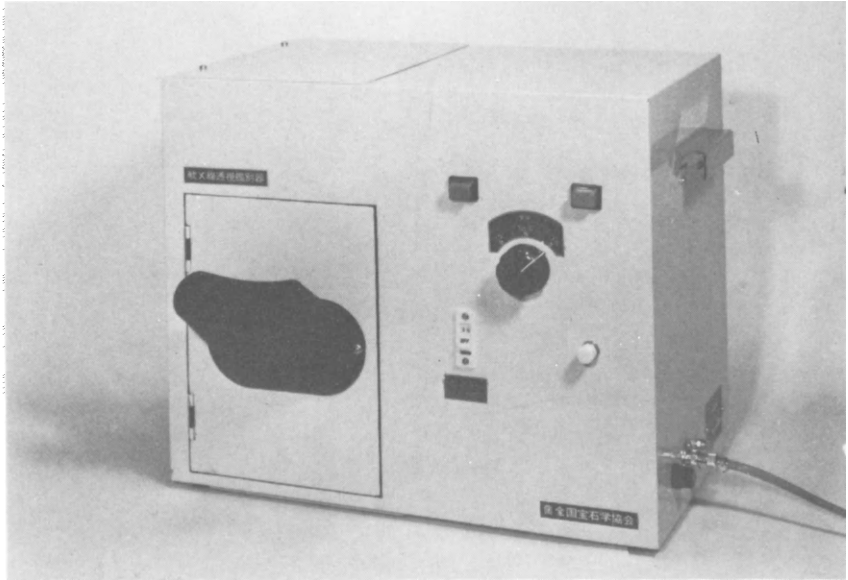
Hydrogrossular garnet glows a characteristic orange under X-ray irradiation.

X-ray unit (GAAJ/Rubin) (*Figure 9.10*)

While this unit is not designed for inspection of fluorescent or phosphorescent properties in gem minerals, it is included here for interest.

This unit is designed to distinguish diamonds (which are transparent to X-rays) from diamond simulants (which vary from opaque to translucent). The X-ray tube is powered from a high voltage 18 kV transformer, and is totally shielded from the viewer. Specimens are placed on a reflecting fluorescent plate inside the unit, and when the 'operate' button is pressed,

Figure 9.10
The low-energy X-ray unit for distinguishing diamond from its simulants by virtue of its transparency to X-rays



the opacity of the specimen can be inspected through the viewing window. For maximum operating life of the X-ray tube, the unit should not be operated continuously for more than 2 minutes at a time.

The unit is designed for 220 V, 50/60 Hz operation, and consumes 300 watts. It is 420 mm wide × 250 mm deep × 360 mm high. ($3600).

References

1. Anderson, B. W. *Gem Testing*, 9th edn, Butterworths (1980).
   Gleason, S., *Ultra-violet guide to minerals*, Van Nostrand, New York (1960). Radley, J. A., Grant, J., *Fluorescence analysis in ultra-violet light*, 4th edn, Chapman and Hall (1954).
   Webster, R., *Gems: Their source, description and identification*, 4th edn, Butterworths (1982)
2. Kodak Wratten Filter No. 47B (blue), No. 25 (red) (see Chapter 16 for more information on filters).

Table 9.1

Manufacturers or suppliers (see Appendix A for addresses)	*LW U-V lamps*	*Combined LW/SW U-V lamps*	*X-ray unit*
P. W. Allen	●		
Eickhorst		●	
Hans-Günter Schneider		●	
Krüss	●	●	
U-V Products	●	●	
R. Rubin		●	●
Gemmological Instruments Ltd	●	●	
Gem Instruments Corp	●	●	
Spectronics Corp/ Orme Scientific Ltd	●	●	
GAAJ		●	●

10 Hardness

Directional hardness. Mohs' scale. Hardness pencils. Hardness test plates.

Gemstones are valued for their beauty, rarity and durability. While the qualities of beauty and rarity would ensure a gem's position in a collection of gem minerals, its durability or hardness is the practical quality which makes it fit to be worn as a piece of jewellery. The surprising degree of wear and tear that jewellery is subjected to in everyday use is due, in part, to the universal presence of minute dust particles of quartz, which act as a fine abrasive on the surface of the gem. In the Mohs scale of hardness, as described in Chapter 1, quartz has a hardness of 7, and for this reason gemstones whose hardness is less than 6 are vulnerable to abrasion.

Because of the knocks to which hand jewellery is subjected, ring and bracelet mounted stones should ideally have a hardness of not less than 6.5. If softer gemstones than this are used in jewellery, the wearer must either take greater care of them, or be prepared to have them re-polished when their lustre deteriorates.

The hardness of a gemstone is due partly to its density, or the closeness with which its constituent atoms are arranged, and partly to its crystal structure. This is demonstrated most clearly in the two crystalline forms of carbon, i.e. graphite and diamond.

Graphite, whose layers of atoms are relatively widely spaced at 0.35 nm (3.5 Å) intervals, has a relative density of 2.2. Diamond, whose atoms are more closely linked at 0.154 nm (1.54 Å) intervals, has a relative density of 3.52. It is also interesting to note that because of its more loosely knit layers of atoms, graphite exhibits perfect 'cleavage' between the layers which shear easily giving it a greasy feel and making it a useful lubricant.

DIRECTIONAL HARDNESS

Some crystalline gem minerals also possess directional hardness, the most dramatic non-diamond example being kyanite which has a hardness of 4 in one direction, and at right-angles to this a hardness of 7. Diamond also varies in hardness, the plane of the dodecahedral face (parallel to the axis of the crystal) being the softest, and the planes of the octahedral faces being the hardest. The difference in hardness between these two directions can be as great as 100 to one. Any changes in the crystal growth of a diamond, such as that which produces 'twinning', will also result in a plane of different directional hardness. All of these factors are of prime importance to the gemstone lapidary and the diamond polisher, who must know precisely the directions for best cutting and polishing.

The fact that diamond, one of the hardest minerals, can be polished at all depends on its directional hardness. Diamond dust, which is used as the cutting abrasive when sawing or polishing diamonds, consists of minute randomly orientated particles of diamond, and this random orientation ensures that some of their edges will be in the direction of maximum hardness when presented to the surface of the diamond being polished. Even if the diamond polisher is forced to polish a diamond facet in the plane of maximum hardness, he will usually be able to offset the polishing plane by a degree or two to obtain a working differential between the hardness of the diamond and that of the diamond dust.

Dependent upon hardness, and the related factors of density and atomic structure, is the degree of lustre that can be produced on the surface of a gemstone. Very soft stones can be difficult to polish, and are limited in their degree of lustre. At the other end of the scale, diamond is one of the supreme gem minerals in terms of the quality of its adamantine lustre.

It should be remembered, however, that even diamond, with its hardness of 10 on the Mohs scale, is not indestructible. Because of its cleavage properties, it is still possible to damage the facet edges, or the culet, of a diamond by an unlucky knock in the wrong place. Zircons, although possessing a hardness of 7.5, have a brittle quality, and, for this reason, loose zircons in a packet should never be allowed to rub against each other, but should be individually wrapped.

The scale of hardness devised by the German mineralogist Friedrich Mohs has been adopted as the main method of classifying the hardness of gem minerals. It should be remembered however that this is not a linear scale, and that the difference in hardness between corundum at 9 and diamond at 10 is many times greater than, say, the difference between quartz at 7 and topaz at 8.

There are other methods of measuring hardness which result in a more linear scale of values, but these are more generally used in industry and in research laboratories. Among alternative methods is a micro-abrasion technique which uses a small cone-shaped grinding wheel to measure the depth of abrasion over a preset time, and a technique which involves the measurement of the deformation produced in the surface of a material when a diamond-pointed indenter is applied to it with a known load.

MOHS SCALE

The method of classifying the hardness of a gem mineral on the Mohs scale is by means of a scratch test. An explanation of how minerals are classified for hardness on the Mohs scale, together with a list of minerals used as standards in the scale, is given in Chapter 1. Unlike all of the other methods for testing a gem's characteristics that have been described so far, this test is a destructive one in that the scratch produced, no matter how small, is a permanent one. For this reason, hardness tests are only made in special circumstances.

In normal circumstances there are usually several alternative identifying tests that can be made on a gemstone, and hardness tests can be regarded as a dubious heritage from the days before other techniques had been developed. Apart from corundum and diamond, there are many stones which have the same, or very similar, hardness, and this renders the hardness test far from specific. There are perhaps two situations in which a hardness test can be condoned. One of these is in the testing of a carving, where other tests may not be practical. In this case a small scratch can be made on the base of the carving. The other valid test is for diamond. As this is the only gem mineral which will scratch corundum, the test is therefore confirmatory.

The popular conception that a diamond can be identified by its ability to scratch glass ignores the fact that several diamond simulants (spinel, topaz, YAG) will also scratch glass. However, if one had a piece of diamond as a comparison, and also had the ability to apply a constant pressure to the gems being tested, there is no doubt that the scratch made on glass by a diamond would be deeper, and that the diamond would 'bite' the glass more positively than other softer gems.

It is instructive to make a series of scratch tests on a plain glass microscope slide, using various pieces of gem minerals, and applying the same pressure for each test. While diamond makes a deep scratch with ease, those made with corundum and topaz become progressively less deep, and when a hardness value is reached which is only one digit higher than the hardness of the glass slide, it becomes quite difficult to start the scratch without applying extra pressure.

HARDNESS PENCILS

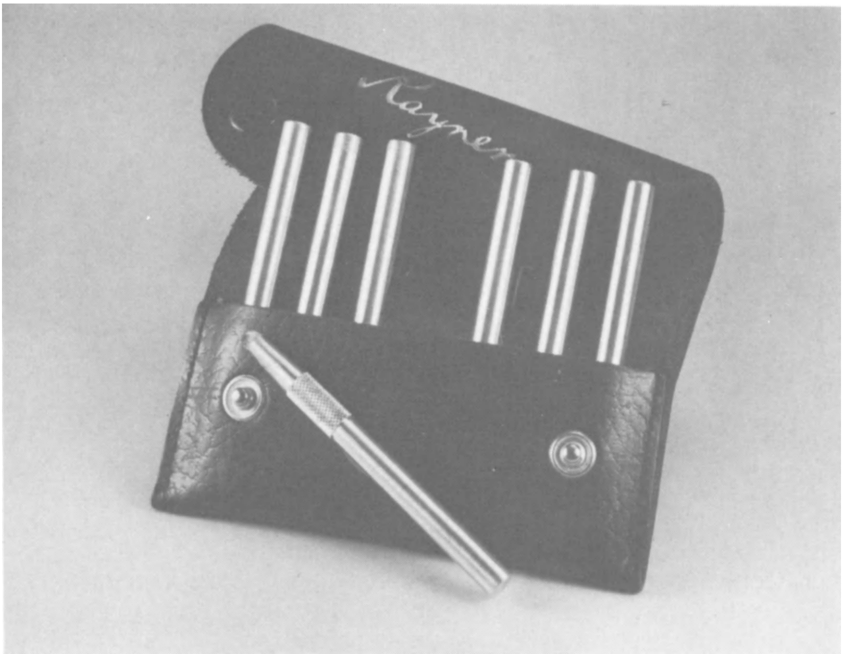
These can be purchased in sets of seven contained in a wallet (*Figure 10.1*) and consist of metal holders in which are mounted pointed fragments of gem minerals. These minerals cover the hardness range of 4–10. They are fluorspar, apatite, feldspar, quartz, topaz, corundum and diamond. The hardness number of each mineral is stamped on the end of the pencils.

When the hardness pencils are used, the gemstone under test should be scratched (preferably in the region of the girdle where the mark will be least visible) starting with the softer pencils and proceeding up the scale until one is reached which just leaves a visible scratch. The hardness of the gem will be somewhere between the hardness of this pencil and the preceding one. The scratch, which should be as small as possible, should be wiped and then inspected with a hand loupe to check that it is a mark on the surface, and not a line of powder from the test point.

Rayner Hardness pencils (Gemmological Instruments Ltd) ($44).
Hardness point set (Gem Instruments corp.) ($55).
Hardness pencils A-1166 (Hanneman) ($35).
Hardness pencils (Krüss) ($52).

Figure 10.1

A set of seven hardness pencils by Rayner (Gemmological Instruments Ltd)



HARDNESS TEST PLATES

As an alternative to the rather risky use of hardness pencils, the hardness of a gemstone can be more safely tested by scratching the flat surface of a mineral of known hardness with the girdle of the gem. A set of hardness test plates can be obtained to order from a lapidary, or, purely as a test for diamond, a polished section of a corundum boule can be purchased. The cost of reasonably large synthetic faceted gems, such as spinel and ruby, is low enough to make even these a source of hardness test surfaces.

When it becomes necessary to identify a gem by means of a hardness test, extreme caution must always be exercised to avoid damaging the stone. This caution applies as much to diamond as it does to the softer gemstones.

A table showing the hardness values of the more important gemstones appears in Appendix B at the end of this book.

11 Thermal conductivity

Thermal conductivity of diamond and other gem materials. Thermal conductivity diamond testers.

Although the measurement of diamond's thermal conductivity has played an important part in the selection of the high-conductivity Type IIa material for use in semiconductor heat sinks[1], it is only in the last few years that this property has been exploited as a means of distinguishing diamonds from their many natural and man-made simulants.

At room temperature, the thermal conductivity of single-crystal diamond varies from 1000 Watts/m/°C for Type I material to 2600 Watts/m/°C for Type IIa material. In comparison, cubic zirconium oxide, the most convincing of the man-made diamond simulants, has the very low thermal conductivity of 10. Of all other possible simulants, corundum has the highest value at 40. Other properties such as thermal inertia are similarly related[2].

The traditional 'breath' test for diamond is also based on the gem's high heat conduction (the rapid dispersion of the film of moisture on the diamond's surface acting as an indicator). This test has been used with varying degrees of success for many years[3]. In retrospect, it is therefore surprising that the unique thermal property of diamond has only just begun to be used in gem test instruments.

The appearance of earlier diamond simulants such as YAG, strontium titanate and GGG no doubt stimulated the design of the now ubiquitous reflectivity meter (see Chapter 6). This type of instrument generally has a test aperture of 1 mm diameter, and this limits the size of the gem which can be successfully checked to around 0.15 carat. An even more restrictive factor with most reflectivity meters is their inability to test recessed stones.

The necessary stimulus for the design of the thermal conductivity tester was probably caused by the growing number of very small (and often recessed) cubic zirconia diamond simulants which began appearing in multi-stone jewellery. In this particular area, the thermal conductivity instrument, with its small diameter test tip, comes into its own, despite its inability to identify the nature of the stone when this is not diamond. It is also significant that the first commercial instrument, the Ceres Diamond-Probe, was designed and marketed by a subsidiary of one of the largest US manufacturers of cubic zirconium oxide[4].

The following notes describe the various commercial instruments which have been produced to distinguish between diamond and its simulants by means of thermal conductivity. In general, the more expensive of these instruments are designed to produce a positive result over a wide range of gemstone and ambient temperatures, while the less expensive versions require more attention to be paid to calibration and the interpretation of results. Some of the simpler models are best used as comparators and should be checked before each test with known test stones (e.g. diamond and sapphire).

With all these instruments, the results are invalidated if the probe tip is allowed to touch the metal surround of a mounted stone, as precious metals have similar thermal conductivities to diamond. With the less expensive versions, probe life and calibration stability is improved if the equipment is switched off when not in use. Some testers are fitted with audible as well as visual indicators, and this allows the user's complete attention to be given to the stone under test. Plug-in test probes are also an advantage in the event of damage to this item. Except where otherwise indicated in the following notes, the minimum size that can be successfully tested is 3 points.

Although this chapter is entitled 'Thermal Conductivity', and this term has been used throughout to describe the test method, there is sound theoretical evidence which indicates that thermal gem probes in fact indicate the thermal inertia of gemstones[2].

COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

The Ceres DiamondProbe (Ceres Electronics Corporation/Eickhorst) (*Figure 11.1*)

This consists of a pen-type test probe and a battery-operated control unit. The control unit contains a large printed-circuit board on which are mounted twelve integrated circuits to provide all the necessary monitoring and control functions. The internal batteries can be recharged from a mains-operated plug-in charger unit, and the probe can be disconnected for transit or replacement purposes.

The test probe contains a 0.5 mm dia. copper tip which is in thermal contact with two miniature thermistors (i.e. ceramic elements whose resistance varies inversely with their temperature). One of these thermistors is fed with pulses of current at one second intervals and acts as a heating element. During the non-heating periods, the resistance of this thermistor is monitored to sample the temperature of the probe's copper tip. The second thermistor is used for temperature compensation.

When the probe tip is surrounded by air, its temperature rises a few degrees above the ambient level as very little heat is being conducted away

Figure 11.1
The Ceres DiamondProbe being used to identify an 0.75 carat diamond

from it. However, if the tip is pressed against the facet of a diamond, each short pulse of heat is conducted away and the temperature of the tip falls. If the probe tip is held in contact with a poor heat conductor, such as a diamond simulant, the tip temperature rises to an intermediate level which is significantly higher than that for diamond.

The effective temperature of the probe tip is displayed on a meter whose scale is divided into three colour zones. If the meter needle comes to rest within the broad red left-hand zone, this indicates that the stone under test is a simulant. However, if the meter needle moves across into the green zone at the right-hand end of the scale, this indicates that the gem has high thermal conductivity and is most probably diamond.

An amber 'buffer' zone separates the red and green sections of the scale. In addition, there are red, green and amber lamps which flash in accordance with the meter reading.

When testing a stone, the probe tip must be held in contact with, and at right-angles to, the gem's surface for at least three seconds until a constant reading is obtained. This enables several successive samplings to be made by the electronic circuits as the temperature of the probe stabilizes. Two test surfaces are provided on the instrument's control panel for checking calibration.

The instrument has built-in thermal compensation which enables it to stay in calibration over an ambient temperature range of 12–32°C. Safety circuits switch off the meter and lamp indicators if the ambient temperature falls outside this range, or if the re-chargeable battery voltage drops below a preset level. The copper tip in the test probe is spring-loaded and retracts into the body of the probe when pressed against the surface of a gemstone.

Because of its various safety circuits the Ceres DiamondProbe is virtually 'operator proof', and will return reliable results with mounted or unmounted stones down to 0.3 carats in size. Its high sensitivity and its disregard of wide fluctuations in temperature (despite the low probe tip temperature) are no doubt a product of the sophisticated circuitry in its control unit coupled with the extremely small thermistors used in the test probe. This latter feature also means that the probe must be treated with some respect as it is liable to damage if dropped. ($825).

The CZeckmate (Ceres Electronics Corporation/Eickhorst) (*Figure 11.2*)

This is a battery-operated pocket-sized model which uses a single flashing lamp in conjunction with an audible 'bleeper' as a test indicator. The instrument's probe tip is protected by a plastic nozzle, and is exposed by rotating the nozzle a half-turn clockwise. This operation also switches the unit on.

When the unit is first switched on, the audio and visual indicators pulse rapidly, but within ten seconds slow to a steady one pulse per second rate, indicating that the instrument is ready for use. The probe tip is then held squarely against the gem's table facet without using excessive force. If the gem is a diamond, the pulse rate of the audio/visual signal will rise

Figure 11.2
The Ceres CZeckmate is a small portable unit which incorporates both an audible and a visual indicator

immediately, reaching a steady high-frequency pitch for large diamonds. If the gem is a cubic zirconia or paste the audio/visual pulse rate will remain unchanged. If it is a sapphire or a zircon, the pulse rate will increase slightly.

As this is a less sophisticated unit than the Ceres DiamondProbe, it is advisable to test a suspect stone several times. A separate mains-operated battery charger unit (adjustable for 120 V and 240 V mains) is supplied, and can be plugged into the rear of the CZeckmate. The recommended operating temperature is 18–24°C. Gems which have been in a hot or cold environment should be allowed to adjust to room temperature before being tested. ($350).

The Dipro (Davenport and Waterhouse Instruments) (*Figure 11.3*)

This unit[5] uses a relatively simple configuration employing an integrated circuit (which contains two operational amplifiers), a power transistor and a voltage stabilizer (see *Figure 11.4*). The probe contains a heating element fed from a non-pulsed current-regulated source. The heating element is thermally in contact with the probe's sterling silver test tip, and the voltage developed across the element is used as an indicator of the probe tip temperature. The operating temperature of the probe tip is fairly high.

The unit's control box is fitted with a meter, and this is fed with the amplified heater element voltage. The meter reading is used as an analogue indication of the rate of fall of the probe tip temperature when testing a stone. If the probe tip is held in contact with a diamond, the meter needle swings clockwise fairly rapidly. If the stone under test is a diamond simulant, the movement of the needle is much slower.

Figure 11.3
The Dipro tester indicates the difference between a diamond and a diamond simulant by the rate of movement of its meter pointer (Davenport and Waterhouse Instruments)

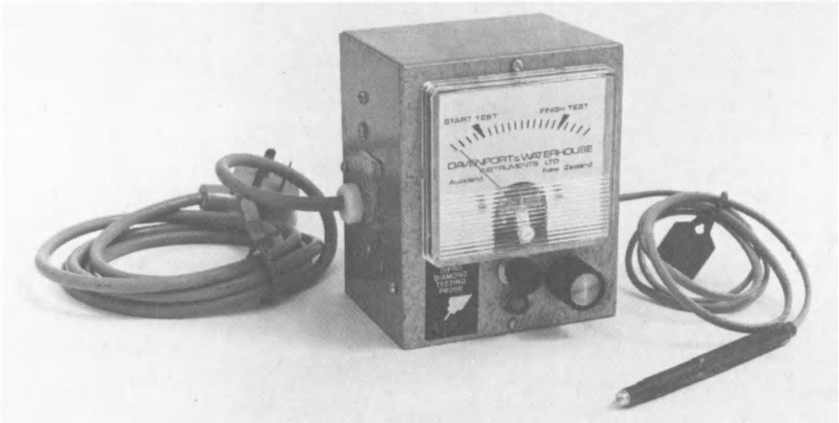
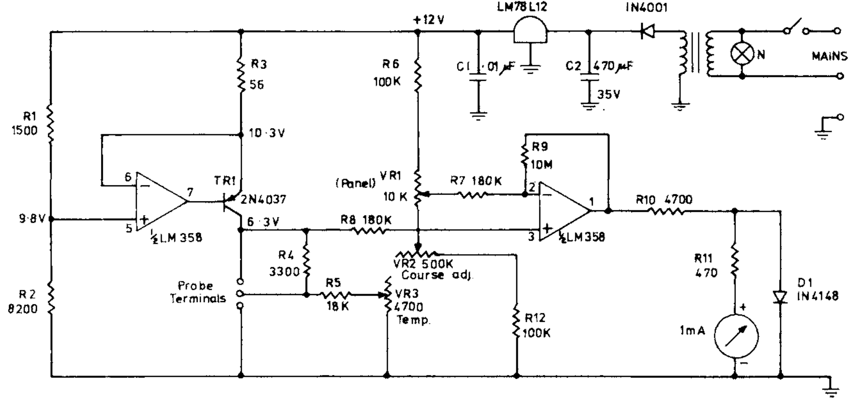


Figure 11.4
Circuit diagram of the Dipro thermal conductivity tester. The integrated circuit section on the left-hand side together with TR1 forms a constant-current source for the probe heater element. The voltage developed across the probe element is amplified by the right-hand section of the integrated circuit and used to drive the meter



After switching on, the Dipro takes some 3½ minutes to reach its operating temperature, this condition being indicated when the meter needle approaches a red 'start test' calibration point at the left-hand end of its scale. A green line at the right-hand end of the scale indicates the completion point of the test, and, for a precise check, the rate-of-swing of the meter needle can be timed between these two points. Diamond can be positively identified by the rapid movement of the meter needle, although the difference in the rate-of-swing for a small warm diamond compared to a large cold sapphire or zircon is less distinctive.

Following a test, some short period must be allowed for the probe tip to reach its operating temperature and for the meter needle to move back towards the left-hand end of the scale. As with other less sophisticated thermal conductivity instruments, stones from a hot or cold environment should be allowed to adjust to room temperature before testing. ($205).

The Rayner Diamond Tester (Gemmological Instruments Ltd/Gemphot/Rubin) (*Figure 11.5*)

This instrument consists of an electronic control unit (containing five integrated circuits and two voltage stabilizers), and a small pen-type test probe in which both heating and thermal-sensing functions are provided by a single glass-bead thermistor. Thermal compensation over a nominal room temperature range of 20–30°C is provided by a second matched thermistor in the probe tip. A user's preset control enables the unit to be recalibrated for ambient temperatures outside this range, and the probe can be unplugged for transit or replacement purposes.

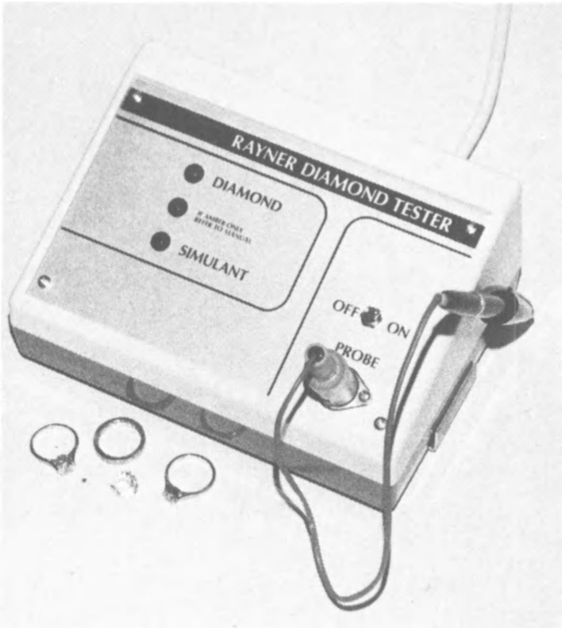


Figure 11.5
The Rayner Diamond Tester MkIII employs a redesigned printed circuit board, an improved probe and an audible indicator (Gemmological Instruments Ltd)

The heater/sensor thermistor is fed with half-second pulses of current at one-second intervals, a sampling pulse monitoring the thermistor's resistance immediately after each heating pulse as a measure of the probe tip temperature. Good heat flow discrimination, at any angle of contact, is provided by the probe's cone-shaped silver tip, which is bonded to the body of the heater/sensor thermistor.

If the probe tip is held in contact with a diamond, the heat energy is conducted away rapidly and the temperature of the tip falls. This fall is detected by the electronic circuits and used to energise a flashing green 'Diamond' lamp on the instrument's control panel and to actuate an audible tone indicator. If the probe tip is surrounded by air, or held in contact with a poor thermal conductor such as a diamond simulant, the tip temperature remains high and a red 'Simulant' lamp continues to flash. A flashing amber lamp, positioned between the green and red lamps provides a 'buffer' zone. If during a test the red lamp extinguishes and only the amber lamp flashes, this indicates that the test is not positive, and must be repeated. From switch-on, the warm-up time is around 60 seconds. Test response time is 4–5 seconds.

Calibration of the instrument is carried out by holding the probe tip in contact with an aluminium test plate, which is also used as a heat sink when testing small unmounted diamonds. The probe tip retracts against an internal spring to protect it from damage.

Earlier versions of the Rayner Diamond Tester were not fitted with the audible indicator, and had a lower probe tip temperature. This made it necessary for the stone under test to be at room temperature for correct operation, and necessitated more frequent re-calibration for ambient temperature changes. The later version operates at a higher tip temperature which enables it to differentiate between small diamonds at body temperature, and large sapphires (which are nearest in thermal conductivity to diamond) at room temperature. ($270).

The Presidium Gem Tester (Presidium Diamond Pte. Ltd.) (*Figure 11.6*)

The unusual feature about this portable battery-operated instrument is that it uses a thermocouple rather than a thermistor as the temperature sensor. The thermocouple is of the copper-constantan variety with two junctions separated by 20 mm. Heat is applied half-way between these junctions by a resistor fed from a constant-voltage source. The resulting voltage output from the thermocouple is amplified and used to drive the meter indicator. The central copper section of the thermocouple is extended at one of the junctions to form the tip of the test probe, and the constantan end wires are formed into a spiral spring against which the 1 mm long probe tip retracts under pressure.

When both of the thermocouple junctions are at the same temperature, they generate the same voltage, and as they are in series opposition, the resulting voltage is zero. If, however, heat is drawn out of the test tip junction, (by, for instance, a diamond) the voltage developed by this section falls, and the overall output voltage rises and causes the meter needle to swing into the green diamond zone of its scale.

When in use, the meter needle swings up to its maximum reading, and then falls slowly back, presumably as heat is also conducted away from the reference thermocouple. For very small diamonds producing a reading close to the red simulant boundary it is necessary to watch for the maximum swing of the meter needle. A fast warm-up circuit makes the test

Figure 11.6
The Presidium Gem Tester is a portable unit employing a copper-constantin thermocouple probe

ready for use within 10 seconds of switching-on. An indicator lamp shows when the warm-up period is completed and also provides a check on the battery condition. Test response time is 2–3 seconds. A plug-in mains adaptor is supplied with the unit. ($350).

The Gem DiamondMaster (Gem Instruments Corporation)

For technical details, see the Presidium Gem Tester. This unit is supplied with a soft vinyl travel case as well as a fitted case. ($375).

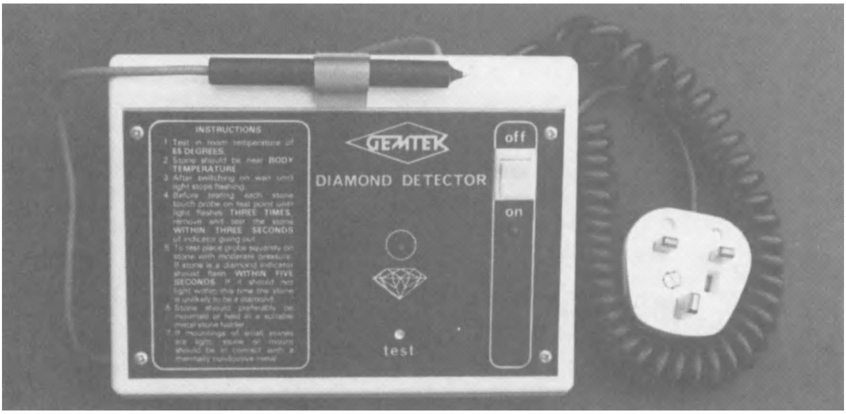
The Diamond Detector (Gemtek Gemmological Instruments) (*Figure 11.7*)

This unit uses a relatively simple circuit in which the voltage developed across a temperature-sensitive semiconductor in the probe tip is checked against a preset voltage in an integrated-circuit comparator. When the probe tip temperature drops (i.e. when it is in contact with a diamond), the voltage across the semiconductor rises above the pre-set level, and the comparator drives a flashing red LED indicator.

The instrument's calibrate preset is not externally adjustable, and the unit is designed for use with stones at body temperature in an ambient temperature above 21°C (unmounted stones should be warmed against the wrist before testing). The test tip operates at a fairly high temperature, and a cooling period between tests is recommended by the manufacturers. Test response time is around 4 seconds.

The tester is available either with rechargeable batteries and a battery charging unit ($280), or as a mains-operated unit ($240).

Figure 11.7
The Gemtek Diamond Detector is available with re-chargeable batteries or as a mains-operated unit (Manvine Holdings Ltd)



The Diamond Proover (Trans-American/Hanneman) (*Figure 11.8*)

This mains-operated 110 V unit uses a very simple circuit in which the heater/sensor in the test probe is a precision voltage-reference diode. Heat is conducted to the stone under test by a copper-wire probe tip which is soldered to the metal case of the reference diode. The diode is heated by a continuous current supply, and its voltage-temperature characteristic used as a measure of the probe tip temperature. When sufficient heat is conducted away from the probe tip by a diamond, an indicator light is energised.

Figure 11.8
The Diamond Proover uses a semiconductor diode in it probe to act as both a source of heat and, via its voltage temperature characteristic, as a thermal detector (Trans-American)

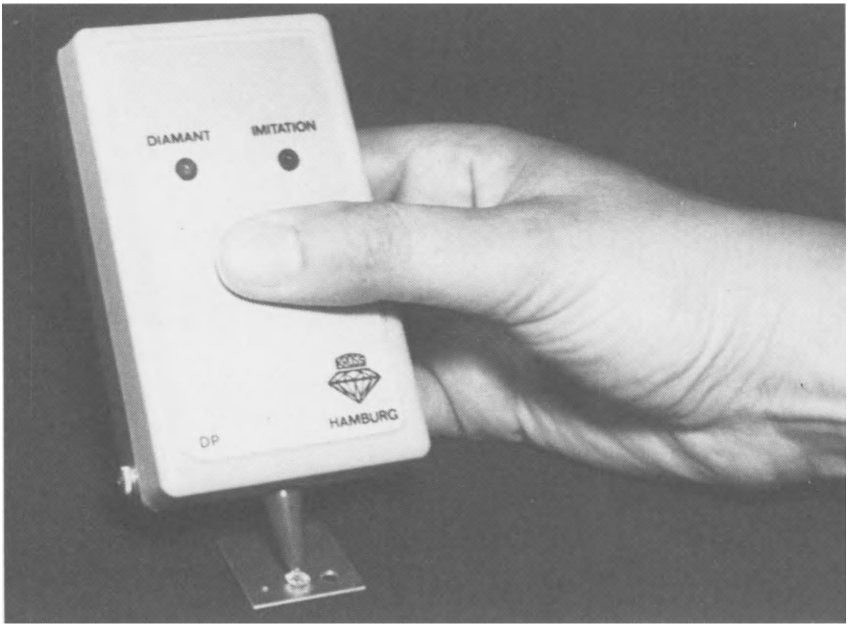
The manufacturers recommend that gemstones are stabilised at room temperature before testing by immersing them in water. When a multi-stone piece of jewellery is checked, stones on opposite sides must be tested alternately to prevent overheating the piece. The probe temperature is surprisingly high, and as the tip is not resiliently mounted, care must be exercised to prevent bending it. Tests at the lower end of the size range are normally limited to 10 points. ($199).

The GfD Diatronic Diamond-Detector (Gesellschaft für Diamantgutachten mbH/Hans Günter Schneider) (*Figure 11.9*)

The GfD unit is a portable model which can be operated from either 220 V mains or batteries, the batteries being re-chargeble and having a four-hour capacity. The unit uses a small test probe which, unlike other instruments, is not pen-shaped. After a 2–3 minute warm-up period, the tester is

Figure 11.9
The GfD Diatronic unit can be operated from either a mains supply or from re-chargeable batteries. It has an audible and a visual indicator

Figure 11.10
The Krüss DP20 is a pocket-sized portable unit employing a test probe which forms part of the control unit



checked by placing the tip of the test probe against the test surface on the instrument's front panel. This causes the yellow 'diamond' indicator lamp to flash and also energises an audible signal. The probe tip is then held for a few seconds against the surface of the stone to be tested. If the stone is a diamond, the indicator lamp and audible signal will again be energised. ($354).

The Diamond-tester DP20 (Krüss) *(Figure 11.10)*

This is a pocket-sized battery operated portable unit in which the test probe has been combined with the control unit. The appropriate 'diamond' or 'imitation' indicator lamp is energised when the unit's test tip is held in contact with a stone. An aluminium test plate is provided for unmounted stones. The manufacturers claim that re-calibration is unnecessary for stones within a size range of 0.03–8 carats. A mains-powered 220 V battery charger unit is provided as standard, together with a carrying box. ($250).

The Diatest 2000 (Darengate Ltd.) *(Figure 11.11)*

The Diatest unit is a pocket-sized tester which can be operated either from a 240 V mains supply or a 9 V battery pack (a 110 V model is also available). The unit's test probe contains a semiconductor diode which is heated from a constant-current source. The probe's copper test tip is soldered directly to the diode's metal casing, and when heat is conducted away from the diode into a diamond, its voltage/temperature characteristic results in the voltage across the diode falling. This drop in voltage is detected by the instrument's electronic circuits and used to energise a green diamond lamp and sound an audible signal.

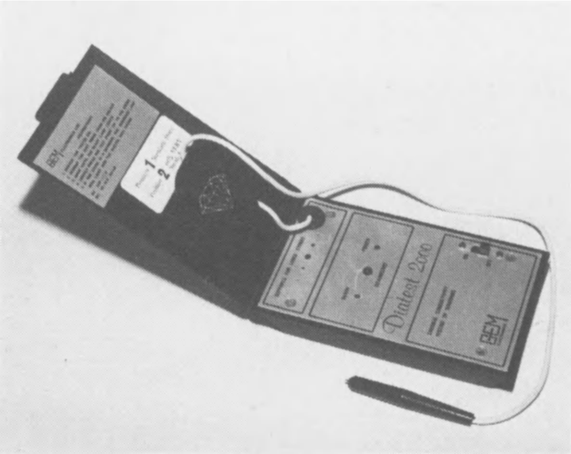


Figure 11.11
The Diatest 2000 is a mains-operated pocked-sized unit which can also be operated from a 9-volt battery pack (Darengate Ltd)

One of the reasons for the good discrimination obtained with the Diatest 2000 is its relatively high tip temperature which enables it to distinguish between a small diamond at body temperature and a large sapphire at room temperature. ($168).

The Vibrograph CD 2000 (Portescap) (*Figure 11.12*)

Designed for re-chargeable battery operation, and supplied with a 110 V or 240 V charger unit, the CD 2000 can be set to provide either a visual or acoustic indication for diamond. The test probe is permanently connected to the control unit and is provided with a protective cap. Warm-up period is 2–3 minutes. ($330).

The Gemmologist (Gemtek Gemmological Instruments) (*Figure 11.13*)

The Gemmologist is the first commercial thermal conductivity tester which not only differentiates between diamond and its simulants, but is also able to identify several of these simulants as well as many coloured gemstones.

As the thermal conductivity of non-diamond stones spans the narrow range of 10 to 40 Watts/m/°C (with diamond between 1000 and 2600), it has been necessary to make the instrument sensitive enough over this range to distinguish between gems whose heat conductivities are close to each other. As a result of this sensitivity, the instrument must be operated within a room temperature range of ±5°F and in an environment free from draughts. The stone under test must also be at body temperature. The instrument functions by measuring the time taken for the probe tip temperature to fall to a preset level.

To ensure the correct functioning of the unit, three indicator lamps are provided above the digital LED display. After initial switch-on, there is an audio bleep signal. This indicates that the unit is operational. After a 5–10 minute pause, a green lamp is energised to indicate that the probe tip has reached its correct operating temperature. The reset button is then pressed to set the display digits to zero, and the probe tip applied squarely to the surface of the gem under test. Should the probe tip temperature rise above a pre-set value, a red indicator lamp is energised. The probe tip is then gently cooled by blowing on it or touching it against the finger tip until the red lamp extinguishes. (Warning: The probe tip is uncomfortably hot!)

For accurate results, the gem under test must be at body temperature, and if unmounted it should be placed on a suitable metallic heat sink. As with the reflectivity meter, some of the indicated readings overlap each other (as can be seen on the table of values printed on the instrument's panel). Despite this, positive separation was obtained during tests between aquamarine and topaz, between blue tourmaline and sapphire, and between ruby and garnet. Flux-melt synthetic emeralds were also distinguished from the natural stone by their significantly lower readings.

Figure 11.12
The Vibrograph CD 2000 thermal test unit (Portescap)

Figure 11.13
The Gemmologist thermal conductivity tester (Gemtek Gemmological Instruments)

Externally adjustable temperature and range calibration presets are provided to enable the user to set the instrument for a specific environmental temperature.

For gems with an R.I. under 1.81, a refractometer undoubtedly provides a far more precise means of identification. However, for diamonds, diamond simulants and for very small coloured gemstones, particularly those mounted in such a way as to make it impossible to check them on either a refractometer or a reflectivity meter, the Gemmologist with its small probe tip can provide additional identification data. ($675).

The Culti diamond selector (Culti Corporation/Geshiro) (*Figure 11.14*)

The Culti Diamond Selector is a small battery-operated unit which can also be powered from the mains via a plug-in adaptor. This model has two unusual features which help to ensure accurate test results. The first of these is its on/off/calibrate control which, in conjunction with a meter indicator, enables the unit's operation to be compensated for both ambient temperature variations and for the size of the stone under test (a table in the operating manual gives the appropriate calibrate settings for the meter).

The second feature represents an innovation for this type of instrument, and consists of a leakage-current type detector which sounds a buzzer if the tip of the test probe touches the metal surround of a mounted gem (a situation which invalidates a thermal test). This detector only functions if the operator is holding the metal body of the test probe in one hand and the ring shank or mount in the other hand. The detector works by applying a small DC voltage between the metal body of the probe and its test tip, and then sensing the very small current (5 to 7 microamps) which flows through

Figure 11.14
The Culti mains/battery diamond selector (Culti Corporation/Geshiro)

the operator's skin when the probe tip touches the hand-held gemstone mount. The correct functioning of this warning circuit, however, depends on a good electrical contact between the probe, the gemstone mount and the operator's fingers. Users with a very dry skin should therefore moisten their fingers before operating the tester!

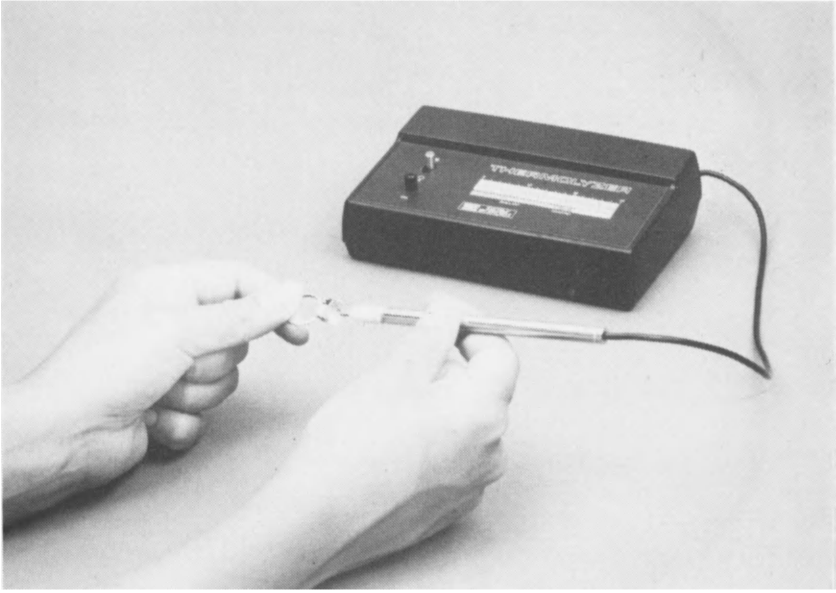
During tests, the Diamond Selector distinguished between small diamonds at body temperature and, among other simulants, a large sapphire at room temperature. A metal test platform is provided for use with unmounted stones. ($200).

The Thermolyzer (Eickhorst) (*Figure 11.15*)

The Eickhorst Thermolyzer is the first commercial thermal gem tester to use a LED bar graph in place of a conventional meter indicator to display the thermal conductivity of a gemstone. This bar graph consists of thirty red light-emitting diode elements which light up as appropriate to distinguish diamond from its simulants. Diamond simulants are indicated in the range 0 to 18, and diamond, which also causes a buzzer to sound, in the range 18 to 22. Higher readings warn that the probe tip is in contact with the metal of a mounted gem.

The unit is easily calibrated by means of an external control knob, and is powered either from the mains via an adaptor, or from internal batteries. ($363).

Figure 11.15
The Thermolyzer with a LED bar graph instead of a conventional meter indicator (Eickhorst)



The Diamond Tester (Gemgold International)

This is a small thermal conductivity tester using a relatively simple circuit which is powered by a mains adaptor. The suppliers warn users that the probe tip is hot, and if touched will burn the skin. They also advise that all stones should be stabilized at room temperature before each test by immersing them in water for 4 to 5 seconds. Diamond indication is by means of a lamp on the control panel. ($200).

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12 Identification of Synthetics and Simulants

Synthetics – alexandrite, corundum, emerald, opal, spinel, turquoise, lapis lazuli, quartz, diamond. Simulants – alexandrite, diamond, lapis lazuli, paste. Composite stones, Artificially coloured diamonds.

While the instruments and techniques described in previous chapters are in constant use for the identification of gemstones and gem minerals, perhaps the most important, and sometimes the most difficult, determinations are those which distinguish between natural and synthetic gems. Although it is also important to identify simulants, these are either gemstones of similar appearance, or paste, and in either case their characteristics are sufficiently different from the gem they simulate to make separation relatively easy.

In the following pages, the various methods of identifying a synthetic from its natural counterpart will be described. This will be followed by some notes on simulants and the detection of composite stones. Finally the production and detection of artificially coloured diamonds will be described.

Tabular information on the R.I., S.G. and hardness of the more common gemstones has been included in Appendix B, and this, together with the information on spectra in Chapter 8 and on luminescence in Chapter 9, should enable these stones to be identified fairly easily. Appendix B also contains a list of typical inclusions in natural and synthetic gemstones.

Although the sequence of the preceding chapters has been planned to follow the order in which an unidentified gemstone would be inspected and tested (i.e. inspection of internal and external features, assessment of general appearance, measurement of refractive index and specific gravity, assessment of spectrum and luminescent properties, estimation of hardness), experience will finally dictate the order and choice of tests.

Some gemmologists, in fact, prefer to use the microscope and spectroscope in their first attempt at diagnosis. A secondary benefit from this approach is that the soft glass of the refractometer table is saved a considerable amount of wear and tear. Once a gemstone has been identified by means of one test, and a confirmation is obtained through a second test, it is pointless to continue with further tests unless it is being done to gain experience. Conversely, it is not wise to rely upon a single test, unless this is a confirmatory one for that particular gemstone (see *Figures 12.1* and *12.2*).

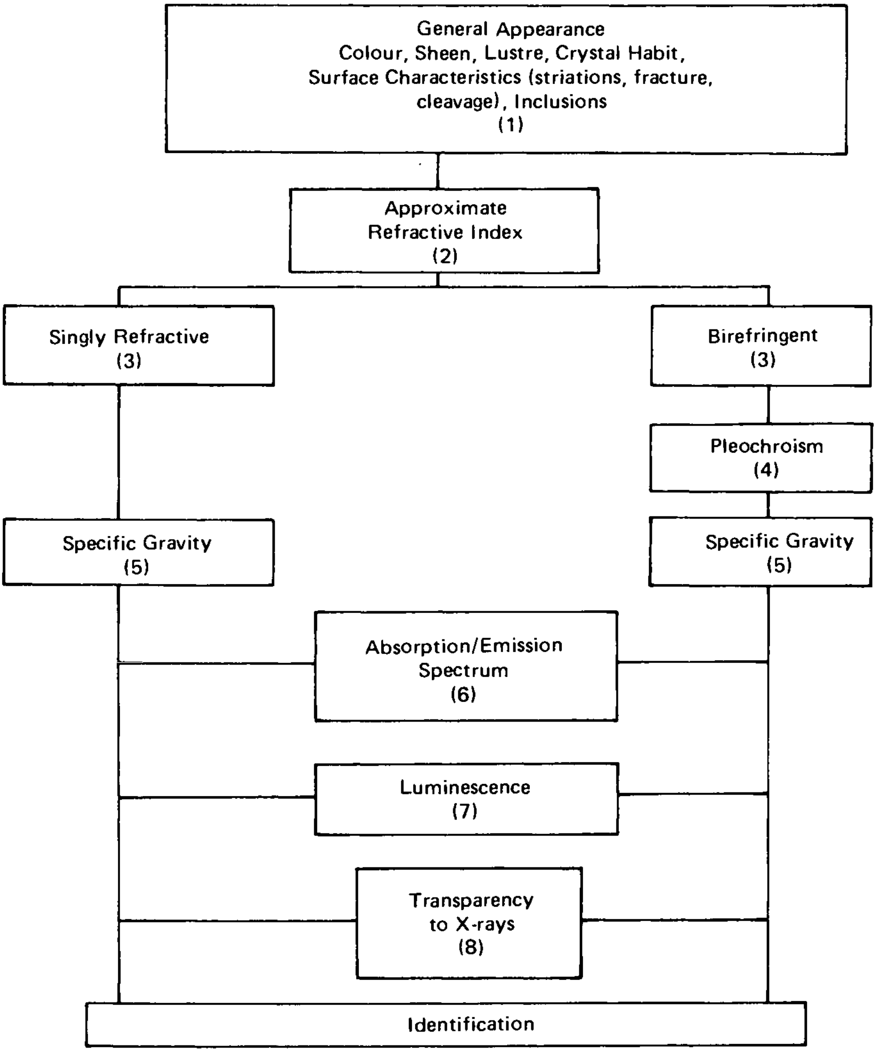


Figure 12.1 Identification routine – unpolished gemstone

1. *Hand lens and microscope; emerald filter*
2. *By immersion (if transparent or translucent)*
3. *Polariscope*
4. *Dichroscope*
5. *Heavy liquids or hydrostatic weighing*
6. *Spectroscope*
7. *Crossed filters; LW and SW U-V; U-V transparency*
8. *Diamond X-ray viewer*

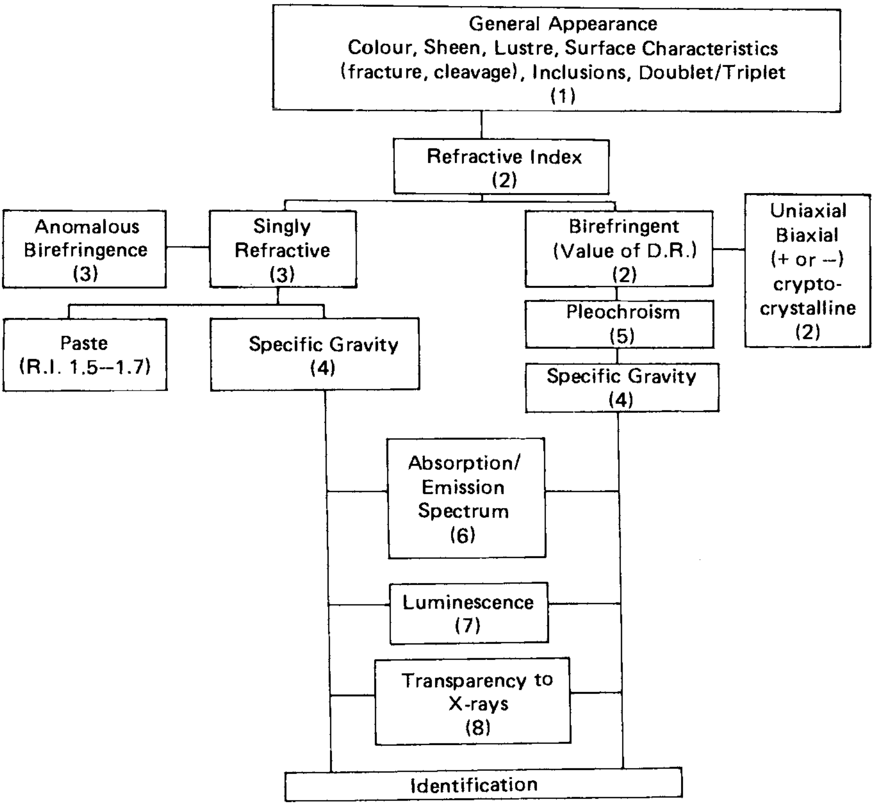


Figure 12.2 Identification routine – polished gemstone

1. *Hand lens and microscope; emerald filter*
2. *Refractometer (relative reflectivity meter for high R.I.s)*
3. *Verify on polariscope*
4. *Heavy liquids or hydrostatic weighing*
5. *Dichroscope*
6. *Spectroscope*
7. *Crossed filters; LW and SW U-V; U-V transparency*
8. *Diamond X-ray viewer*

SYNTHETIC ALEXANDRITE

This is a true synthesis of the rare gem alexandrite, and unlike the corundum and spinel simulants, exhibits the exact colour change of natural alexandrite (i.e. pale green in daylight to a brownish red in incandescent light). It is made by a flux-melt process, and although it has all the physical characteristics of fine Siberian alexandrite, the R.I. is reported to be 0.02 lower than that of the natural variety. Under the microscope, the synthetic appears to be characterised by swarms of tiny inclusions (apparently parallel to the seed face) similar to those found in synthetic emerals and flux-grown rubies; banding or growth lines can also be seen[1,2,4]. Some stones contain lines of parallel negative crystals (see also U-V transparency tester in Chapter 16).

SYNTHETIC CORUNDUM

Ruby and sapphire (blue, pink, yellow and bluish green) are mainly produced by the Verneuil flame-fusion process, although ruby can also be made by the flux-melt and hydrothermal processes.

It is both unfortunate and a challenge that the physical properties of synthetic corundum are identical to those of natural ruby and sapphire. The spectrum of natural and synthetic ruby is also identical except that the synthetic stone, being rich in chromic oxide, normally shows the lines in the red and blue more clearly. Synthetic yellow sapphires however are coloured with nickel (and not iron as is the case with the natural stone) and do not show the typical three iron absorption bands in the blue, or indeed any other absorption bands or lines. Similarly synthetic green sapphires are coloured with copper and not iron, and are also lacking in the iron absorption bands. Synthetic blue sapphires, containing virtually no iron, show no trace of iron bands.

Fortunately it is possible to see signs of the crystal growth processes in many synthetic corundums, and this, together with a knowledge of the types of inclusion to be found in natural rubies and sapphires, is perhaps the most positive way of separating synthetic from natural.

A descriptive list of the inclusions in natural rubies and sapphires is given in Appendix B which also gives an indication of the country of origin. Natural rubies often show 'silk' inclusions (see under 'Inclusions' in Chapter 1) and sapphires sometimes show rutile needles and liquid feathers. Both ruby and sapphire may contain crystal inclusions.

In flame-fusion corundums careful observation under the microscope will often reveal curved colour zones. These colour zones are most clearly seen in blue sapphire, but are rarely present in ruby or yellow sapphire. In synthetic flame-fusion rubies, careful orientation of the stone (preferably while immersed) will often reveal fine concentric growth lines. In natural sapphires, parallel colour zoning is often visible, and in larger stones can be seen to follow the hexagonal structure of the crystal. Other inclusions in flame-fusion corundums are flask- or tadpole-shaped bubbles, and clouds of very fine particles (unmelted powder). Because of the way in which the stones are cut from the boule (with the table facet parallel to the principle axis), dichroism shows through the table facet of a synthetic corundum instead of through the girdle as with a natural well-cut stone.

The Plato test can be used to identify flame-fusion synthetic corundums containing no inclusions or detectable curved stria. In this test the direction of the stone's optic axis is found with the aid of a konoscope (see Chapter 5). The stone is then viewed under crossed polars at 20–30× magnification while immersed in methylene iodide. If two sets of lines intersecting at 60° are visible when viewing the stone in a direction parallel to the optic axis, the stone is a synthetic Verneuil corundum.

Flame-fusion synthetic corundums can also be detected by their complete absence of iron oxides which unlike the majority of natural stones makes them highly transparent to SW U-V (see U-V transparency tester in Chapter 16).

Kashan rubies produced by the flux-melt process are more difficult to identify as they contain iron oxides in varying amounts, which produce a range of colours and SW U-V transparencies (as with the natural stones). The only unique inclusion to be found in some Kashans is a very coarse solid-filled negative crystal. Other Kashan inclusions such as 'rain' or 'dust' and rod-like parallel crystals are occasionally found in natural rubies. A ruby containing an abundance of 'silk' is more likely to be a natural ruby as silk is only found in small quantities in Kashans. 'Paint splash' inclusions may also be present and consist of flux residues.

SYNTHETIC EMERALD

Emeralds can be produced by the flux fusion or the hydrothermal processes. Although the Lechleitner emerald (produced by hydrothermally depositing a thin layer of synthetic on a piece of poor quality natural emerald) and the Linde emerald (also hydrothermally grown) have the same physical properties as natural emerald, the other synthetics (Chatham, Gilson and Zerfass) have a lower R.I. (1.560–1.563 compared to. 1.577–1.583) and a lower S.G. (2.65 compared to 2.71).

If bromoform is diluted to an S.G. of 2.65 with quartz as an indicator, Chatham, Gilson and Zerfass emeralds will float. Separation can also be made with a refractometer test, particularly if the more open scale of the spinel version is used. These emeralds are also more transparent to SW U-V light than is natural emerald, but this particular test involves the use of immersion contact photography (i.e. the natural and synthetic emeralds are placed side by side on a piece of photographic paper, which is placed in the bottom of a shallow dish containing water; this is then exposed for two or three seconds to SW U-V light). (see also U-V transparency tester in Chapter 16). Inclusions are limited to veil-like feathers.

In the Lechleitner emerald, it should be possible to see the natural beryl base or seed crystal (usually light in colour or transparent). Parts of the rear facets of the stone may be left unpolished in order not to weaken the colour. Networks of fine cracks may also be visible. If the gem is immersed in bromo-benzene (having an R.I. of 1.56), the dark rim of the emerald coloured synthetic beryl can be seen.

The Linde type synthetic emerald has very noticeable red fluorescent properties, which can be seen even in white light.

The Regency emerald[4A] is a newer synthetic produced by Vacuum Ventures using the hydrothermal process. It is distinguished by its fine bluish-green colour, by cuneate growth-tubes and by two-phase inclusions stemming from phenakite crystals. S.G. is 2.67 to 2.69; R.I. 1.57, 1.576.

A descriptive list of the inclusions to be found in both natural and synthetic emeralds appears in Appendix B, indicating, in the case of the natural stone, the country of origin. The range of inclusions met with in natural emeralds includes thin liquid films resembling paving stones, two-phase inclusions resembling commas and three-phase inclusions, crystals, crystal 'blades', fibres and mica particles. Emerald simulants can be detected by the use of the Chelsea filter as described in Chapter 4.

SYNTHETIC OPAL

The 'Gilson' synthetic opals are produced as both white and black stones of very convincing appearance. Under a high-magnification (60×) microscope, the structure lines within the yellow colour segments of the older type white Gilson opal resemble a series of closely spaced gullies reaching down from each side of a central spine. The structure within an orange segment of the newer white gilson opal, however, has a crazy-paving appearance[3].

Gilson opals are made from sodium silicate or a silicon ester which is then slowly dehydrated. The tiny particles produced are similar to the cristobalite spheres in natural opal, and as they are extremely small (0.0002 mm diameter), they are only visible with the aid of a high-power instrument such as an electron microscope. In both synthetic and natural stones these spheres are arranged in regular rows of similar size and produce the opal's play of colour by means of diffraction and interference of the reflected light.

Although, in the main, the physical properties of synthetic and natural opals are too similar to allow separation by a simple diagnostic test, W. F. Eppler[4] has found that synthetic opals tend to be softer than naturals, with a hardness of 4.5 as opposed to 5.5–6.5. The main identifying features of Gilson synthetic opals, as sumamrised by E. A. Jobbins, P. M. Statham and K. Scarratt[5], are mainly of appearance, and their classification relies on the use of the microscope. These features are as follows:

1. The stones show a mosaic comprising equidimensional or 'blocky' structures viewed from above or below.
2. Many white synthetics show a pronounced columnar structure when viewed from the side.

3. Some white synthetics show a distinctive dendritic structure at higher magnifications in transmitted light.
4. By transmitted light the grains often have finely crenellated edges giving them a 'dried leaves' effect.
5. In later black and white synthetic opals the grains have a 'lizard skin' appearance seen under magnification by both transmitted and reflected light.
6. Many Gilson opals have high porosity and tend to stick to the tongue. This effect is not so marked in many natural stones.

It is also possible on occasions to use opal's luminescent properties to separate naturals from Gilson synthetics[6]. As all samples of Gilson synthetic opals fluoresce a 'dusty' green colour (similar to that shown by paste imitations) under SW U-V, and a few fluoresce under LW U-V, any opals which show *no* signs of fluorescence under LW or SW are naturals.

When a natural opal *does* fluoresce under U-V (usually with a white or cream shade) it also phosphoresces. This phosphorescence, as viewed under dark conditions, continues for a period of approximately twelve seconds. Signs of phosphorescence were virtually non-existent in Gilson specimens (which were of the darker composition approaching black opal).

It has also been noted[6] that in the columnar structure of synthetic opals, the colour in each column is the same in any direction. In the rare natural specimens which show a columnar structure, the colour varies from point to point.

As both synthetic and natural opals are very porous, extreme caution should be exercised when immersing them in any liquid. For this same reason no attempt should be made to clean them in an ultrasonic bath.

SYNTHETIC SPINEL

Like synthetic corundum, synthetic spinel is produced by the Verneuil flame-fusion process. As the colours in which synthetic spinels are produced are intended to simulate those of the more expensive gemstones, they are generally quite different from those found in natural spinels. Fortunately, because of the large amount of alumina used in the growth of the synthetic spinel boule, its physical properties are markedly different from those of natural spinel:

Natural spinel	*Synthetic spinel*
R.I. = 1.717	R.I. = 1.727
S.G. = 3.6	S.G. = 3.64

A refractive index test therefore forms a positive means of identifying a suspect stone. In addition, because of the method of manufacture, synthetic spinels often contain internal stresses which are revealed as an anomalous birefringence under a polariscope. This is a patchy, cross-hatched variation in light transmission which occurs when rotating the stone between crossed polars and has been aptly named 'tabby extinction' by B. W. Anderson.

Although spinels of a wide variety of colours have been made by the Verneuil method, red ones are rare as they tend to fracture at the boule stage.

Spinels have also been grown by the flux-fusion process, and these include red spinels which, unlike their natural counterparts, do not show the typical fluorescent 'organpipe' spectral lines.

Diagnostic inclusions in natural spinels are tiny spinel octahedron crystals (in Burma reds), which form a ghost-like feather, and spinel crystals arranged in lines (in stones from Sri Lanka). Spherical gas bubbles may occasionally be seen in synthetic spinel.

SYNTHETIC TURQUOISE

Gilson synthetic turquoise at 50× magnification is seen to contain small dark blue angular particles in a white background 'matrix', a structure quite unlike that seen in natural turquoise. Where the necessary equipment is available, identification can also be made by means of infra-red reflection spectroscopy. All natural turquoises show three distinctive reflection peaks at 9500 nm, 10 300 nm and 11 200 nm, while synthetic turquoise shows a broad peak with a maximum reflection at 11 200 nm[7].

The specific gravity of one sample Gilson turquoise was found to be in the region of 2.635 (compared with 2.8 for natural) and its R.I. was 1.592 (compared with 1.62)[8]. Other samples have averaged 2.74 and 1.60 respectively[9]. Unfortunately, both of these constants are characteristic of natural turquoises from America and it would seem that the best test that can be made is a visual examination (at about 50×) for the characteristic dark blue particles in a whitish groundmass exhibited in Gilson synthetic turquoise[9, 10].

More recent investigations[10A] have shown that the Gilson product consists mainly of calcite, and should therefore be more correctly designated as a simulant rather than a synthetic.

SYNTHETIC LAPIS LAZULI

Gilson synthetic lapis lazuli has as its chief ingredient the mineral lazurite (which is also one of the constituents of the natural rock). In a destructive test, the crushing of Gilson lapis produced a strong sulphurous smell, unlike its natural counterpart, in addition, the synthetic version reacted far more strongly to a spot of hydrochloric acid than did the natural lapis, and its S.G. was much lower[11].

A series of tests made on both synthetic and natural lapis lazuli[12] has shown that the synthetic version has a relatively high porosity (natural lapis has none), is less dense than natural (S.G. is approximately 2.36 compared with 2.8) and that it reacts more rapidly to sulphuric, nitric and hydrochloric acids. Because of its relatively high porosity, it has been more accurately described in some literature as a lapis substitute.

Mr. H. Andersen[13] has given the following hints for recognising the Gilson synthetic lapis lazuli:

1. A very good violet colour, comparable with the finest lapis lazuli.
2. A better lustre than the natural lapis (more like sodalite).
3. The pyritic inclusions can be scratched with a needle.
4. The white inclusions are like longish clouds, not comparable to the natural inclusions.
5. The 'streak' (made by rubbing a fragment against a piece of white unglazed porcelain, called a streak plate) is dark blue instead of light blue.
6. X-rays show it as an amorphous (X-ray transparent) substance.

SYNTHETIC QUARTZ

Synthetic quartz is grown hydrothermally, and has been produced for many years for the optical and electronic industry. More recently, both the Americans and the Russians have manufactured quantities of gem quality quartz in gem colours. As the cost of the synthetic quartz is close to that of the natural variety, there is less concern in the identification of a synthetic quartz gem, except perhaps for amethyst. This is perhaps fortunate, as their physical properties are, as might be expected, identical.

The colourless seed plate is usually visible in uncut synthetic quartz material, and this is accompanied by strong colour banding parallel to the plate. Examination of a faceted synthetic citrine under a binocular microscope, using dark-field illumination, showed small groups of 'bread-crumb-like' inclusions[14]. Natural amethyst can sometimes be confirmed by the presence of a characteristic 'tiger stripe' inclusion, or lamellar growth indications under polarised light.

SYNTHETIC DIAMOND

Although at the time of writing, the synthesis of gem diamond has not yet occurred on a commercially viable scale, a few diamond grading and gemstone testing laboratories (such as the Independent Gemstone Testing Laboratory in Hatton Garden, London) have prepared for this eventuality by studying the few available laboratory-grown gem quality synthetic diamonds[14A]. These studies hve revealed that inclusions, crystal structure (via Nomarski interference contrast surface inspection), X-ray and UV phosphorescence and spectrum analysis using a spectrophotometer, could be used to positively distinguish between natural and synthetic diamonds.

ALEXANDRITE SIMULANTS

Both synthetic corundums and synthetic spinels are produced which, by means of a trace of vanadium, imitate the characteristic colour change in the alexandrite variety of chrysoberyl. However, where alexandrite changes from a pale greenish colour in daylight to a brownish red in incandescent light, synthetic corundum shows a markedly different change from a washed-out greyish blue in daylight to an amethyst purple in filament light. Synthetic spinel more nearly matches alexandrite by changing from green to red. However, the spinel simulant does not exhibit the strong pleochroism shown by alexandrite (red, yellowish-red, green in filament light).

Alexandrite is more dense than spinel (3.72 against 3.64) and less dense than corundum (4.0) and can be separated in this way. Although alexandrite and corundum have similar R.I.s (1.745–1.754 against 1.760–1.768) spinel can easily be identified at 1.727.

DIAMOND SIMULANTS

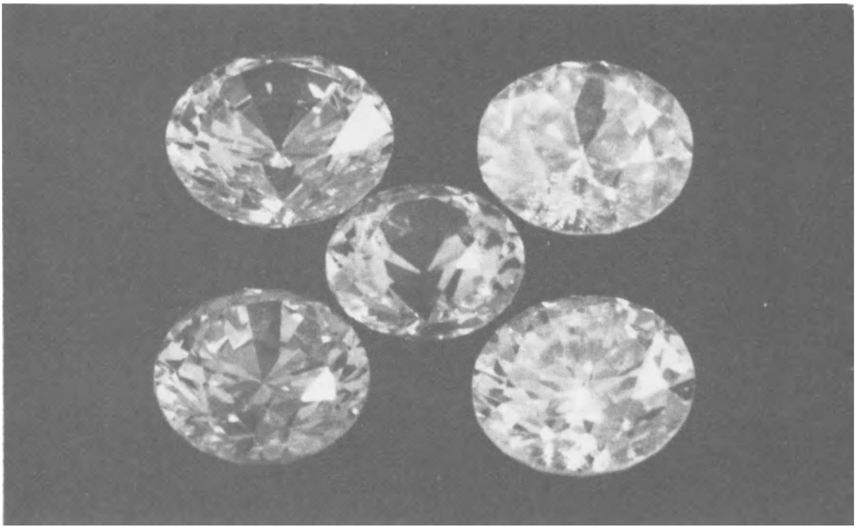
Diamond, because of its beauty when correctly cut, and its value, is probably the most imitated of all the gemstones. Unlike emerald (of perhaps even higher value) there are no commercially available synthetic gem diamonds (yet!), although both the Americans and the Russians have produced laboratory-grown gem quality specimens in the one carat size range.

Because of the very special optical properties of the brilliant cut diamond (assuming a close approximattion to ideal proportions) and the dependence of the ideal proportions upon the high R.I. of diamond (2.42), it is possible to make a simple and often quite effective test for simulants known as the 'tilt' or 'light spill' test.

If the alleged diamond is positioned with its table facet upwards, it is not possible to look down through the diamond (unless the culet is exceptionally large) as the pavilon facets act as reflecting mirrors. If the diamond is now moved so that the eye begins to look through the table facet at an increasing angle to the normal, it should still not be possible to see out through the pavilion (even at angles approaching 90 degrees) if it is a genuine diamond. With other colourless gemstones, which are cut to the same proportions as diamond (to imitate it), the optics of the brilliant cut fail owing to the lower R.I. of the stone (except for strontium titanate), and it is possible to see through the sides of the pavilion facets at quite a small angle to the normal (i.e. these will appear black, see *Figure 12.3*).

Strontium titanate, a synthetic with an R.I. of 2.41, is much softer than diamond (5.5 against 10), which eventually results in the chipping of the facet edges due to wear. It can be easily identified by its large dispersion (0.19 against 0.044) which gives it excessive fire. Size for size, it is also appreciably heavier than diamond.

Figure 12.3
The 'Light spill' test is illustrated here with a diamond (bottom right) and four stimulants. In the centre is a YAG, bottom left is cubic zirconia, top right lithium niobate and, top left, GGG.



White zircon is a convincing simulant in terms of fire as its dispersion is 0.039, but as it has very strong double refraction (0.059) it is easily distinguishable, the doubling of the back facets being almost visible to the naked eye.

Yttrium aluminium garnet (YAG) is another popular diamond simulant and is certainly a little nearer to diamond's hardness at 8.5, but has noticeably less fire (dispersion of 0.028). Because of its greater hardness it takes a better polish and is more durable than strontium titanate. It has a much lower R.I. (1.833) and although it is off the scale of the standard refractometer, it is possible to use this property to check the comparative visibility of the stone when immersed in a clear liquid having a refractive index of, say, 1.74 (methylene iodide). If the stone is a diamond, its outline will stand out clearly, but if it is a simulant with a much lower R.I., this will tend to become invisible in the liquid.

Synthetic white spinel is a passable simulant in that it is singly refractive and is reasonably hard (8.0), but it has a low dispersion (0.020). As it has an R.I. of 1.727 it is easily checked on the refractometer.

White sapphire (synthetic or natural) has an excellent hardness (9.0) and would therefore exhibit less signs of wear and tear than any other diamond simulant. Its dispersion, and therefore its fire, is low (0.018), and as it has a low R.I. (1.76) and is doubly refractive, it is easily identified.

White topaz has a reasonable hardness (8.0), but its dispersion is even lower than sapphire, and as it is doubly refracting and has a measurable R.I. (1.61) it is again easily distinguished.

Quartz is another possible simulant, but with a low dispersion, double refraction and a measurable R.I. (1.54), it can quickly be separated.

Surprisingly enough paste, or faceted glass, has a dispersion high enough (0.031) to give it sufficient fire to simulate diamond. As it is an amorphous substance, it is also singly refracting like diamond, but its R.I. is low enough (1.6) to be measured. The softness of paste (5.0) also gives it away as the lustre and the facet edge sharpness are much inferior to those of diamond.

Gadolinium gallium garnet (GGG) is yet another singly refractive colourless synthetic with a relatively high R.I. (1.97). It is also the heaviest of the simulants, with an S.G. of 7.05. Its dispersion at 0.045 is very close to that of diamond. GGG is mainly distinguishable by its 'heft', or feeling of weight, and by the slight brownish tinge to its body colour. It also fluoresces a weak orange under LW U-V[15, 16] and a distinctive peach colour under SW U-V. If left too long under a SW U-V lamp, GGG turns brown (it reverts to its colourless state again after a few hours).

Lithium niobate is another possible synthetic diamond simulant. It has rather too much fire (dispersion of 0.120), is relatively soft (5.5), and its high double refraction (0.09) makes it easily distinguishable.

Cubic zirconium oxide is a relatively new and convincing diamond simulant[17], having a good hardness (8.5), a high R.I. (2.18) and being singly refracting. It can be distinguished from diamond by its 'heft' (S.G. of 5.7), and by its opacity to both U-V and X-rays.

A set of seven boxed diamond simulants are available from Gem Instruments Corporation ($110).

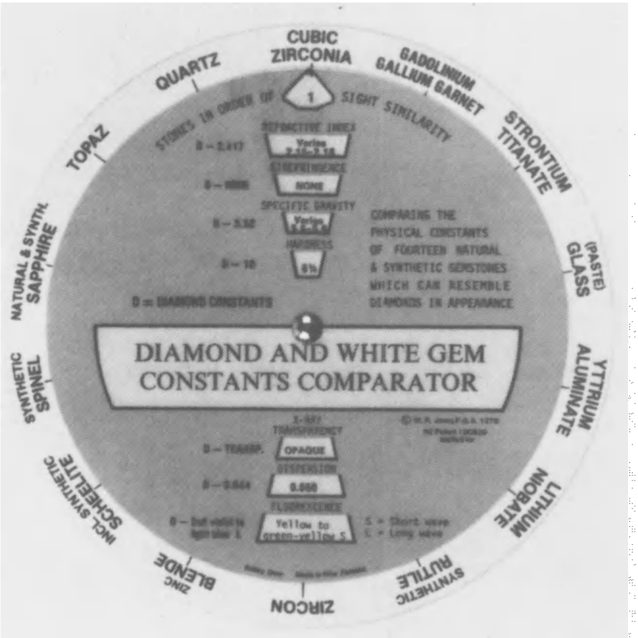


Figure 12.4
Diamond Comparator disc (Gemmological Instruments Ltd)

One confirmative test that separates diamond from all its simulants is a check for transparency to X-rays. Diamond is the only gem mineral that is completely transparent to X-rays, and this is due to the regular simplicity of its lattice structure and the low atomic number (6) of the constituent carbon atoms. A suitable X-ray equipment designed for diamond testing is described in Chapter 8. Other useful tests for diamond are its distinctive reflectivity (see Chapter 6) and thermal conductivity (see Chapter 11). Used in combination these last two tests are confirmative. It should also be remembered that diamond is the only blue fluorescing gem mineral that phosphoresces yellow.

A Diamond Comparator disc (*Figure 12.4*) provides a rapid means of comparing the R.I., D.R., S.G., hardness, X-ray transparency, dispersion and fluorescence between diamond and 14 possible simulants (Gemmological Instruments Ltd. $7).

An additional characteristic that can be used to separate diamond from its high R.I. simulants is its low water-contact angle. This is exploited in a special ink dispensing pen test described in Chapter 16.

LAPIS LAZULI SIMULANTS

A synthetic spinel simulant is made by heating magnesium and aluminium oxides with cobalt oxide (as a colouring agent) and copper flakes (to imitate pyrite). If the temperature is held just below the melting point of spinel, a sintered granular product results which has an appearance not unlike that of lapis. The R.I. of spinel (1.727 compared with 1.5 for lapis)identifies the simulant as does its hardness (8 against 5.5).

Another simulant, known as 'Swiss Lapis', is a blue-dyed jasper. It does not exhibit lapis lazuli's pyrite inclusions, and its R.I. is slightly higher at 1.54. Another simulant is sodalite which is a constituent of lapis. This can be separated by means of its specific gravity. Lapis has an S.G. of 2.8, and is heavier than sodalite at 2.28.

OPAL SIMULANTS

The slocum stone[18A] is made from treated glass, and is easily distinguishable from natural opal by its rather gaudy and unconvincing appearance. The manufacturing process produces extremely thin parallel layers within the glassy matrix, and these are the cause of the material's irridescence. It can also be identified by its R.I. (1.52) and S.G. (2.50). Bubbles are also present within the material.

A Japanese opal simulant[19] has been made from monodisperse polystyrene latex, but unlike the natural stone does not appear to be porous, and has a glossy appearance. One distinctive feature consists of markings which resemble streaks made by an unevenly applied paint brush.

PASTE SIMULANTS

Apart from its use as a diamond simulant, glass can be coloured to match most of the more common gemstones. One tell-tale check for glass is to look for signs of bubble inclusions, or colour swirls, with the aid of a microscope. As glass is rather brittle, and relatively soft, there will also tend to be damage, perhaps in the form of characteristic conchoidal fractures, to the facet edges.

Glass is amorphous, and a paste simulant will therefore be singly refracting, and will never show dichroism, which will serve to distinguish it from some of the stones it simulates. As there is no singly refracting natural gemstone which falls within the range of R.I.s covered by pastes (1.50 to 1.70), an R.I. test can also be confirmatory. On the polariscope, paste gems will usually exhibit an anomalous birefringence in the form of a distinctive cross pattern caused by internal strains.

COMPOSITE STONES

Except for the rare case where a composite stone is formed by two sections (crown and pavilion) of the same mineral, which are cemented together to form a larger whole ((and opal doublets and triplets), these stones are fabricated with the intent to deceive.

Composite stones can consist of doublets (as just described), whose crown can be of the mineral being faked, and whose pavilion can be of a cheaper mineral, such as quartz, or even a synthetic (i.e. a diamond crown and a YAG or synthetic white sapphire pavilion).

Opal doublets are formed from a thin top layer of precious opal backed with common or potch opal, the latter being hidden by the mount. Opal triplets are formed by cementing a dome of clear quartz to the thin top layer of an opal doublet. In this case, the top of the composite stone shows no sign of iridescence, and a 'distant vision' R.I. reading for quartz can be obtained from this face.

A range of doublets has been produced using a coloured glass pavilion to which is fused a thin crown section of garnet. These are described as garnet-topped doublets. The high garnet lustre of the table enables them to simulate ruby, blue sapphire, emerald, peridot, citrine and topaz, with the appropriately coloured glass pavilion. They are identified readily by the high R.I. reading of the table facet, by the presence of bubbles and colour swirls in the glass pavilion, and by other typical composite-stone characteristics (referred to in the next paragraph).

Triplets, such as the soudé emerald, consist of a quartz, a synthetic white spinel or a colourless beryl top, with a quartz or spinel base. The emerald green colour is produced by a green colouring layer between the crown and the pavilion. Although it is convenient to form a doublet or triplet with the joint around the girdle (which can be more easily hidden by the mounting) it is possible to find the join higher up in the crown. R.I. readings of the crown will usually reveal the fraud (except in those cases where the crown is of the simulated gem material). Careful examination of the stone immersed in monobromonaphthalene or water will usually show any differences in body colour between the two halves. Further examination of the stone with a hand loupe, or under a microscope, will reveal the junction. This may also be indicated by a plane of bubbles where the two halves have been fused or cemented together.

ARTIFICIALLY COLOURED DIAMONDS

Perfect diamonds are colourless in that they do not selectively absorb any wavelength in the visible region of the spectrum. Bombardment of a diamond with high energy radiation, whether produced naturally or artificially, causes the stone to become coloured. The artificial production of colour centres in diamond has been studied in detail for three types of radiation, fast neutrons, fast electrons and gamma rays[18]. Neutron irradiated diamonds appear green, while electron or gamma irradiated stones have a blue-green colour.

The production of colour, or colour change, in diamond is the result of the radiation introducing defects into the lattice. The defects, which may be stable up to temperatures of 600°C, can become mobile within the lattice at higher temperatures, and the heat treatment of stones which have been turned green through irradiation can produce a more attractive shade of yellow or amber.

The colour produced by electron or gamma ray bombardment is only skin deep and can be polished off. Colour produced by neutron bombardment, however, penetrates the whole body of the stone and causes short-term radioactivity. The protons, deutrons and alpha particles generated by a cyclotron can also be used to change the colour of a diamond, the resulting green shade again being only skin deep. Like neutron-irradiated stones these rapidly lose their initial radioactivity.

With all these irradiation-type colour change processes, the resulting colour, although more pleasing in hue, is never lighter than the diamond's original natural colour. More recently, however, experiments in the research laboratories of the American General Electric Company have shown that the yellow tints of Cape Series diamonds can be lightened by a high temperature/high-pressure annealing process[19].

The detection of diamonds which have been artificially coloured by irradiation and then heat treated, is by means of the spectroscope, which shows a diagnostic line at 594 nm, (together with the original line system at 415.5 nm if the stone was orginally a yellow 'Cape'). However, if the heat treatment temperature reached 1000°C, this diagnostic line disappears[19]. The diamond must then be cooled towards liquid nitrogen temperatures to reveal other diagnostic lines[19A].

A blue-green stone can be proved to be artificially coloured if it acts as an electrical insulator, as all naturally occurring blue diamonds are Type IIb and will pass an electric current. If a diamond has been cyclotron-irradiated through the side of its pavilion, a zone of colour will be apparent near its girdle; if irradiated through the table, a dark ring will be visible on looking at the pavilion side of the stone. If the diamond has been treated through the pavilion at right-angles to the girdle, a scalloped shape will be seen round the culet on looking down through the table.

Diamonds can of course be coloured by other means than irradiation[20]. To make a diamond appear more white, a translucent coating may be applied to its pavilion, the colour of the coating being the compliment of the body colour of the diamond. Such coatings can be removed by solvents such as alcohol or acetone.

A more scientific coating is the anti-reflection fluoride composition that is applied to camera lenses. A bluish fluoride coating applied to a yellow diamond will, by the mixing of the two complimentary colours, make the diamond appear less yellow. The coating can be detected as it kills the adamantine lustre of the surface to which it is applied. It can be removed by treatment in hot acid.

INFORMATION SOURCES ON SYNTHETICS AND SIMULANTS

For further information on the detection of synthetics and simulants, reference should be made to B. W. Anderson's 'Gem Testing' and to its French translation by C. A. Schiffmann 'Identification des Pierres Precieuses'. In order to keep abreast of new materials and testing techniques it is also advisable to read the journals produced by the various Gemmological Associations (see Appendix A).

Mr. M. J. O'Donoghue produces two regular Newsletters which, as they appear at more frequent intervals than the Journals, are even more topical. The one entitled 'Gemmological Newsletter' contains information on new synthetics and rare minerals, together with reviews of new gemmological and mineralogical books. The other publication 'Synthetic Crystals Newsletter', deals exclusively with all synthetic crystals, and not just the gem variety. Both newsletters are distributed worldwide. Enquiries should be made to M. J. O'Donoghue, 7 Hillingdon Avenue, Sevenoaks, Kent, TN13 3RB, England.

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13 Experimental Instruments

Air-boundary refractometer. Brewster-angle refractometers. 'Direct method' R.I. vernier gauge. LED refractometer light source. Phosphoroscope. Computer-aided gem identification.

Many useful gemmological instruments, some of them no more than gadgets, have been constructed from time to time to serve a particular need. A few have been exploited commercially, but the majority, perhaps because of the difficulty of translating them economically into saleable pieces of test equipment, have remained as interesting one-off prototypes. An historic example of this is L. C. Trumper's visual reflectivity comparator, which anticipated the introduction of the electronic reflectivity meter by some fifteen years.

The following notes describe a selection of such instruments for the benefit of those who may wish to experiment along similar lines.

Air-boundary refractometer[1] (R.M.Yu and D. Healey)

This represents an interesting attempt to overcome the contact liquid and prism material limitations of the critical angle refractometer. The instrument uses the phenomenon of total internal reflection in a faceted gemstone to measure the stone's R.I. in terms of its critical angle.

Two steps are involved, the first of which consists of measuring the pavilion angle θp. To do this the gemstone is placed table facet down on the instrument's test platform, and a horizontal beam of light is directed at the pavilion facet (*Figure 13.1*). The user looks through an aperture in the instrument's cursor (*Figure 13.2*), and moves the cursor until a mirror image of the light source can be seen in the pavilion facet nearest to the light source. The pavilion's angle θp is then read from the lower cursor scale.

The second step consists of switching on a light source immediately beneath the gemstone, and moving the cursor until its aperture is immediately above the gemstone. If the R.I. of the gem is lower than 2.37, the pavilion will appear bright when viewed through the aperture (if it is above 2.37 the pavilion will appear dark). For gem's having an R.I. less than 2.37, the cursor is moved towards the left-hand end of the scale until the lower girdle facets, as viewed through the aperture, just begin to turn dark. At this point the R.I. of the gem is read from the cursor's position against the appropriate θp section of the scale. For gems having an R.I. greater than 2.37, the cursor is moved to the right until the lower girdle

Figure 13.1
In the air-boundary refractometer the pavilion angle θp is measured by means of a horizontal light source A, whose reflected image is viewed in a moveable aperture at C

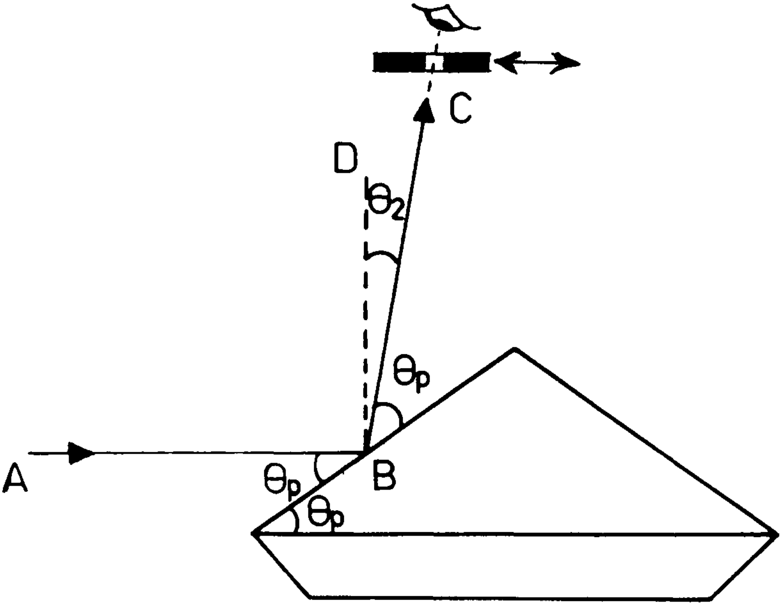
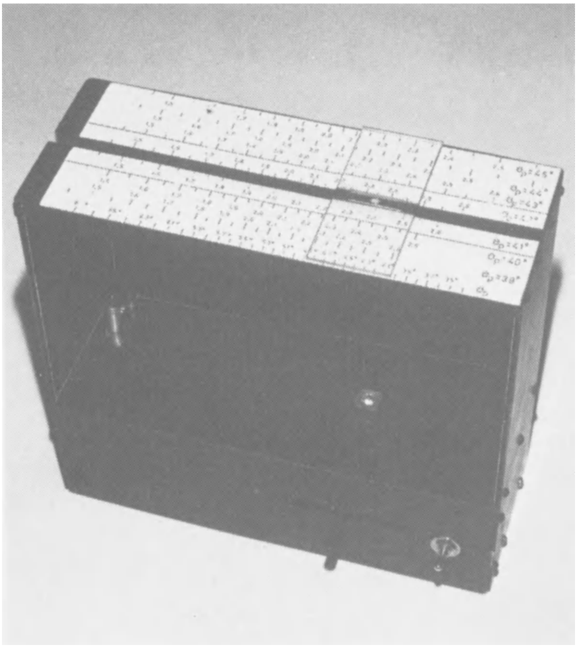


Figure 13.2
The air-boundary refractometer showing a gemstone positioned centrally on the test plate. The cursor scales consist of the pavilion angle θp scale at the lower edge, followed by the appropriate θp RI scales. The cursor is fitted with a central viewing aperture



facets just begin to turn bright, and the cursor reading again taken against the appropriate θp scale.

The accuracy of the instrument is limited to ±0.02 (compared with ±0.001 for a standard refractometer), and it cannot be used on cabochons, or on fancy cut stones with pavilion facet angles outside the range of 37–45°.

Brewster-angle refractometer[2] (P. G. Read)

Brewster's law states that complete polarisation of a ray reflected from the surface of a denser medium occurs when it is normal (i.e. at right-angles) to its associated refracted ray within that medium (*Figure 13.3*). If the Brewster angle of polarisation is *A*, then the R.I. of the reflecting medium is equal to *tan A*, and this provides an interesting mechanism by which to arrive at a gemstone's refractive index.

Although B. W. Anderson had already proved that a gemstone's R.I. could be measured by this method[3], the technique did not appear to have been developed because of the mechanical difficulty in rotating a beam of light about the surface of a gemstone while simultaneously following the movement of the reflected ray with a suitable polarisation detector.

The author's version consists of a simple optical model (*Figure 13.4*) which dispenses with a moving detector and passes the reflected rays through a suitably orientated polarising filter, imaging the result as a travelling spot on a translucent screen (*Figure 13.5*). With a gemstone positioned over the test aperture, the angle of the incident beam is then

Figure 13.3
Sketch illustrating the polarisation of a reflected light ray. This occurs at the Brewster-angle (A) when the reflected ray R is normal to the refracted ray C in the reflecting medium

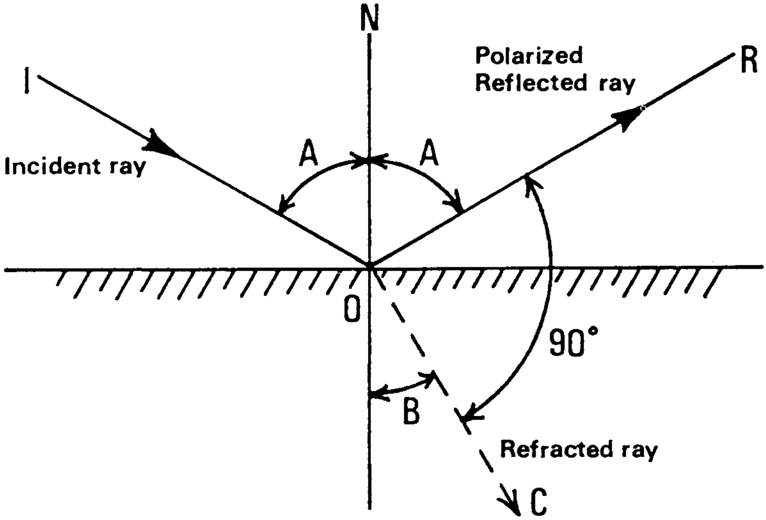


Figure 13.4
An experimental Brewster-angle refractometer. The angle of a thin collimated ray of light is pivoted around the plane of the gem's table facet. The reflected ray is imaged via a polarising filter and viewed through the eyepiece lens. The prism (lower left) allows for simultaneous viewing of the instrument's scale

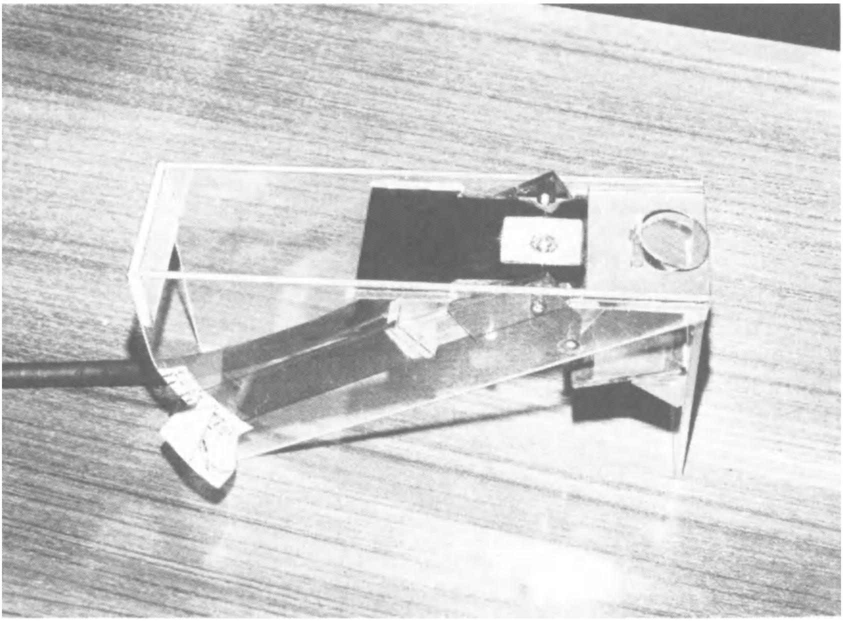
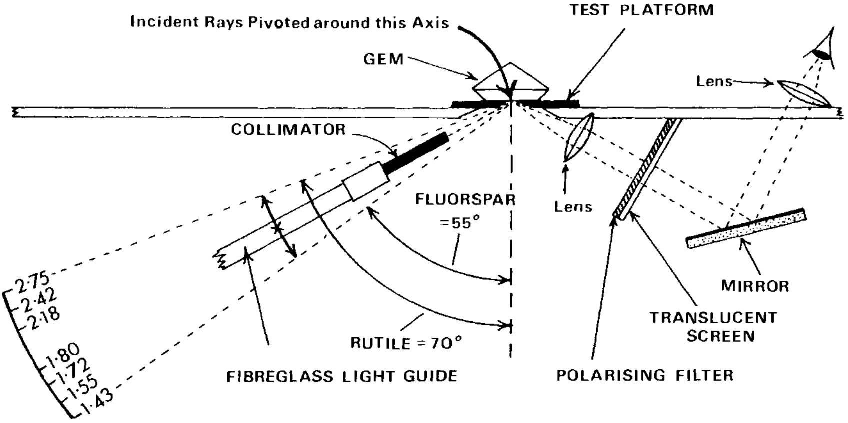


Figure 13.5
Sketch showing the layout of the experimental Brewster-angle model in Figure 13.4. A small light-baffle (not shown) is fitted beneath the gem test aperture to prevent spurious reflections from reaching the screen



adjusted for extinction of the reflected light spot, the extinction or Brewster-angle being used as a direct measure of R.I.

While not accurate enough to detect double refraction, the experimental model was (in contrast to the reflectivity meter) relatively insensitive to scratches or dirt on the gemstone's surface, which simply reduced the sharpness of attenutation of the spot at the polarisation angle.

Brewster-angle refractometer[4] (R.M.Yu)

This is an even simpler method of using the phenomenon of Brewster-angle as a means of determining a gem's R.I. In this version, a graduated transparent scale is illuminated by a fluorescent lamp whose light is diffused by means of a strip of translucent white plastic. Light from the illuminated scale is reflected from the polished surface of the gem and viewed through an appropriately orientated polarising filter. As the various points on the scale subtend different angles to the reflecting surface, the observer sees a dark band on the otherwise evenly illuminated scale, this band occurring at angles of viewing close to the Brewster angle for the gem. The position of the band on the scale can therefore be used as an indication of the gem's R.I., and the scale can be calibrated accordingly.

In an alternative arrangement, the viewing polariser is dispensed with, and a strip of polarising filter is placed in front of the upper half of the illuminated scale. This enables the dark band to be viewed above the calibrated section of the scale, the latter remaining brightly illuminated.

'Direct method' R.I. vernier gauge (H. Bartman)

For those who do not possess a microscope fitted with a dial gauge for focus depth measurements, an alternative instrument for the measurement of a gemstone's refractive index by the 'direct method' (see Chapter 5) can be produced reasonably cheaply by modifying a vernier caliper gauge (*Figure 13.6*). The modification consists of mounting a hand lens (having at least a 10× magnification) to the top moveable section of the gauge, and fitting a suitable clip to hold the stone or ring shank to the body of the gauge.

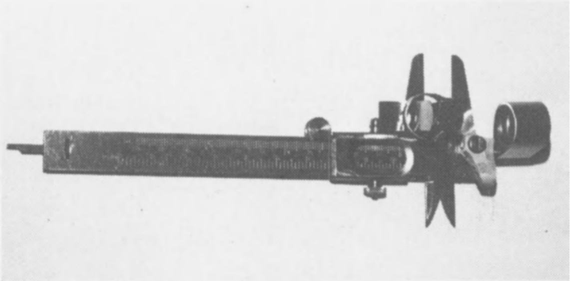


Figure 13.6
The 'direct method' of R.I. measurement is used on this vernier caliper gauge which is fitted with 10× lens and a ring shank/gemstone holder

The gauge is first used conventionally to measure the true depth of the stone. The stone is then fitted in the clip, table facet uppermost, and the gauge adjusted until first the table facet and then the culet is in focus. The readings from these two settings are taken off the vernier scale and subtracted from each other to obtain the apparent depth of the stone. As with the microscope method, the stone's R.I. is equal to the real depth divided by the apparent depth.

LED refractometer light source[5] (D. Minster)

This unit uses six yellow light emitting diodes (LEDs) as an alternative light source for the refractometer. In the version which the author built to test D. Minster's design, the LEDs and their associated components were assembled in a bell-type transformer unit of convenient shape (*Figure 13.7*). A mains-powered rather than battery-operated circuit was chosen (*Figure 13.8*), because the LEDs' electrical characteristics dictate their connection in parallel, and this increases the total current drain to 120–200 mA.

In choosing the yellow LEDs, it is preferable to select those having a peak emission reasonably close to the sodium wavelength of 589.3 nm. The LEDs used in the test unit were Vitality type CM4-582B with an emission peak centered on 585 nm. If the light output is checked with a wavelength spectroscope, the response of these lamps will be seen to extend from 560 to 640 nm (which corresponds roughly to the measured transmission response of the Rayner yellow eyepiece filter).

Tests made with the unit produced refractometer shadow edges less sharply defined than those obtained with either a sodium light or an interference-filtered lamp. The LED unit, however, has the advantages of cheapness, robustness and portability. (*Two commercial LED units have subsequently been marketed – see Chapter 5*).

Figure 13.7
An experimental yellow LED light source used with a Rayner Dialdex refractometer

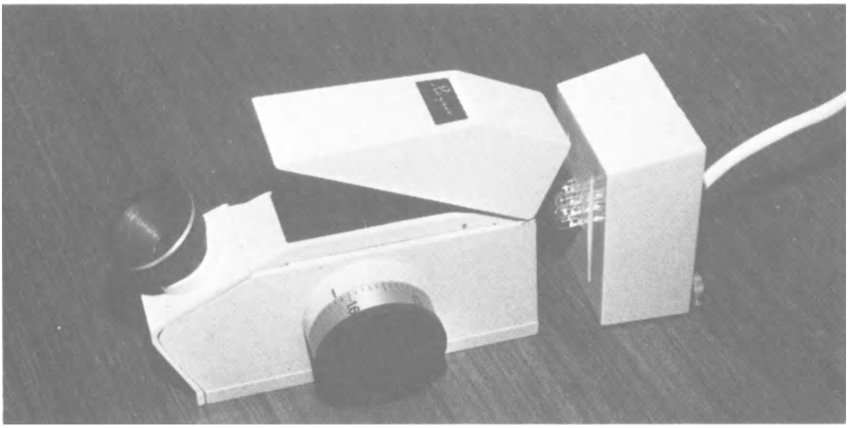


Figure 13.8

Circuit diagram of a mains-powered LED refractometer light source. Series resistors limit the LED current to around 20 mA. The silicon rectifier diode 1N4001 prevents reverse voltages appearing across the LEDs

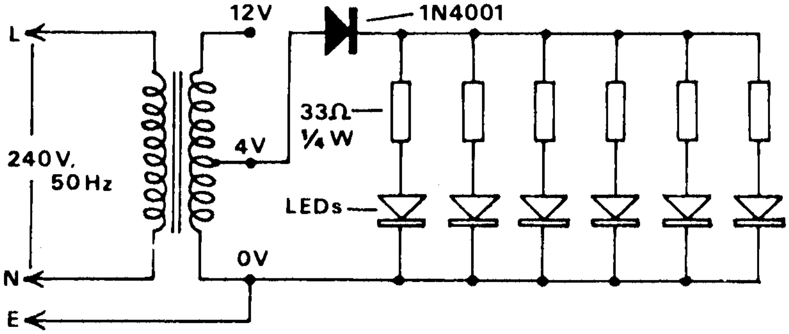
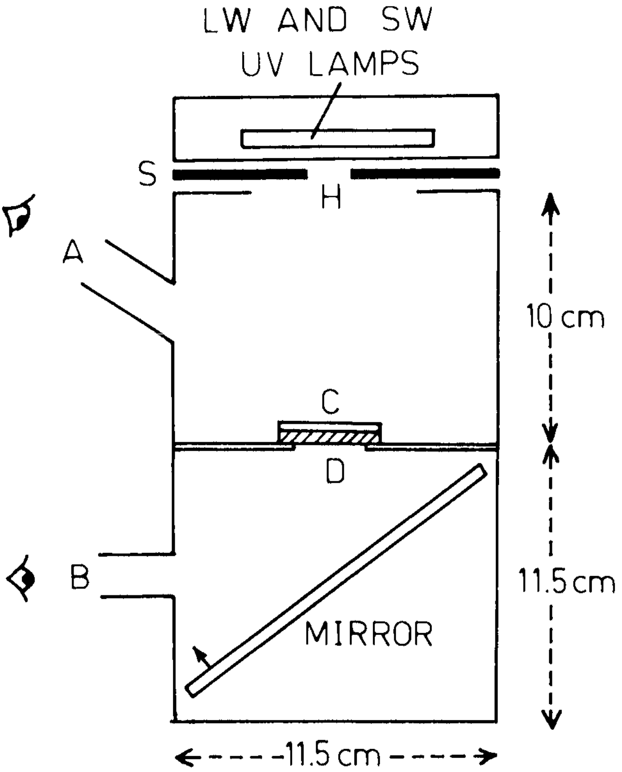


Figure 13.9

Construction of the Phosphoroscope. Port A is used for normal fluorescent viewing. Port B is used for assessing U-V transparency by means of the phosphorescent paper C.



Phosphoroscope[6] (R.M.Yu and D. Healey)

The phosphoroscope provides a convenient means of viewing both the LW and SW U-V luminescence of gemstones, and at the same time of checking their transparency to U-V.

The phosphoroscope consists of a wooden box (*Figure 13.9*) with matt black inner surfaces. The upper section containing viewing port *A* is hinged open to enable gems to be placed on a thin sheet of phosphorescent paper *C*, supported on a glass slide *D*. Any ultra-violet light passing through the gem will cause the paper C to phosphoresce, and this can be viewed through port *B* (or photographed) via a 45° mirror and the glass slide *D*.

For normal U-V luminescent work, the phosphorescent paper is covered with a black cloth, and the gemstones placed on top of the cloth. (see *also the Culti Color Stone Checker in Chapter 16*).

Computer-aided gem identification (P. G. Read)

The author's own experience in computer programming served as a starting point for an attempt to develop computer programs which would act both as a convenient source of gem data, and as a means of identifying an unknown gemstone from test measurements.

The first two programs GEM DATA 1 and GEM DATA 2 were produced essentially for student use[7]. They were written in BASIC for an Exidy Sorcerer computer having a 32k memory, and were recorded on the two sides of a standard tape cassette at 1200 baud. The GEM DATA 1 program was a data bank and contained three separate sections. The first of these consisted of gem 'Profiles', and contained 'pages' of data on over seventy gem species or minerals which were displayed on a video monitor. An index was used to select and display the required gem data pages, each of which commenced with a single-line specification giving R.I., D.R., dispersion, S.G., and hardness. The page then listed the chemical formula, crystal system, optical character and optic sign for the selected gem. This was followed by information on the gem's lustre, cleavage, colour varieties and pleochroism.

The second section of the GEM DATA 1 program contained eight pages of gem constants arranged in tabular form, the first four pages being in alphabetical order, the second four in order of ascending R.I. The final section of the program enabled single-line gem specifications to be selected from the index and displayed adjacent to each other for comparison purposes.

The GEM DATA 2 program was a diagnostic one, and aided the identification of a gemstone under test by matching its measured constants (fed in via the keyboard in response to the program's questions) with data contained in lists of constants held in the computer memory. When this program was in use, the computer requested, in sequence, the values of the gem's mean R.I.,D.R., and S.G.

To allow for instances where it was not possible to measure R.I. or S.G., a '9' was keyed in which instructed the computer to by-pass this section. If it was only possible to detect that the gem was singly-refractive, doubly-refractive or crypto-crystalline (by means of a polariscope), then an '0', a '1', or a '9' was keyed in respectively when the computer requested the value of the gem's double refraction.

To accommodate variations (or errors) in test measurements, and to allow for a spread in values caused by gem impurities, a choice of two 'search tolerance' limits was available in the computer program. A narrow search request caused the keyed-in data to be matched against the stored data over the limits of ±0.005 for R.I., ±0.002 for D.R. and ±0.02 for S.G. For a wide search, these limits were broadened to ±0.01, ±0.004 and ±0.04 respectively. If no match was found by the computer between the keyed-in data and the data in its memory, an appropriate message was displayed on the video monitor.

After these two computer programs had been in use for some months it was decided to develop a professional version which would contain at least three times as much data, and would have a faster method of loading the program into the computer (the tape cassette method took up to five minutes to load).

To achieve this, a 5¼-in (16-sector) Micropolis floppy disk unit is now used to store the new programs, and the computer memory has been expanded to 52k (*Figure 13.10*). The professional GEMDATA 1 data bank

Figure 13.10
The author's gem data computer installation

program is contained on three magnetic disks. An extended BASIC language occupying 20k of memory is used to allow the program automatic access to sections of data from the disks.

In the GEMDATA 1 program over 200 gem minerals are covered, each page (or set of pages) being retrieved from the disk store on the entry of the appropriate index number (*Figures 13.11* and *13.12*). Information on each gem 'profile' has been extended to include fluorescence, absorption spectra and occurrences. In the constants section, gem specifications are displayed in order of rising S.G., as well as rising R.I. and alphabetic order. An additional 'Gem Calculations' section enables hydrostatic weighing results, reflectivity, critical angle and Brewster angle to be computed from input data.

The diagnostic section of the program has also been re-structured to contain data on over 200 gem minerals, including rare and collectors' stones. All the main features of the student level program are retained, but with doubly-refracting gems each R.I. value (rather than a mean R.I.) is keyed in (*Figures 13.13 and 13.14*). To accommodate gems with wide variations in R.I. and S.G., the necessary tolerances are automatically allowed for in the stored data, which contains both the minimum and maximum values normally found. For doubly-refracting stones, the program also asks for the gem's optic sign, and an optional input of '0' can be used if this is not known. In the S.G. section, provision is also made for tests using heavy liquids, a number code being used in place of an S.G. value.

To accomodate the wider errors associated with the 'Direct Method' of R.I. approximation, when a wide search limit is selected for gems with an R.I. over 1.80 the R.I. limits are automatically broadened to ±0.1. For a wide search limit,the S.G. limits have also been broadened to ±0.06 in the new program.

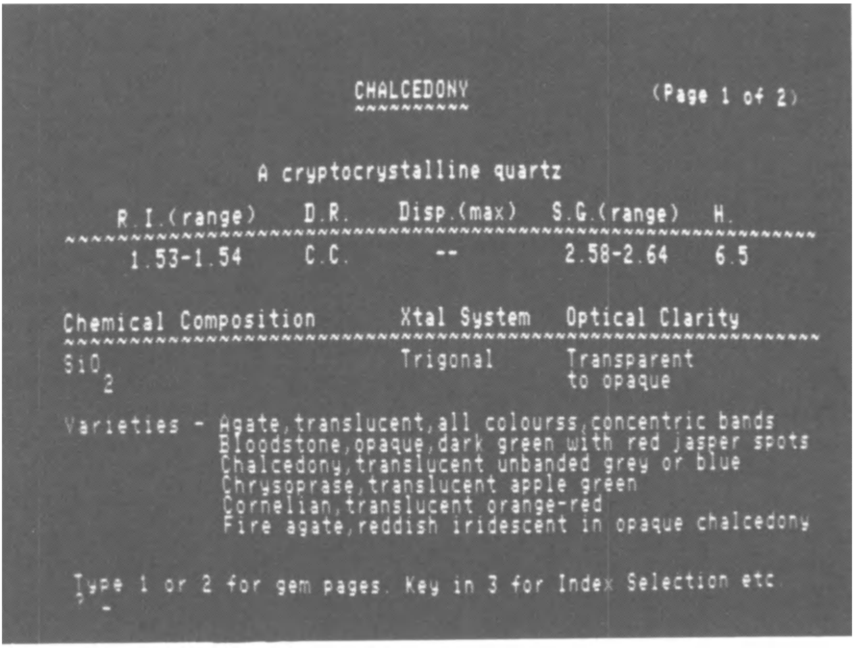
As with the student version, the professional gem identification program allows for a degree of data manipulation in which a list of gems can be obtained having, for example, a cryptocrystalline character, or a particular range or R.I. or S.G., regardless of other parameters.

Because of the large increase in stored data in the professional version of the GEM DATA program, it may take up to 20 seconds for the computer to match the keyed-in values for R.I., D.R., Optic sign and S.G., and to provide one, or several, possible identifications. However, this is still considerably faster than a manual search through tables of gem data.

From experience gained with the new program it would seem that it could form a very useful adjunct to normal gem testing procedures, and is certainly helpful in prompting possible identifications in the case of the 'difficult' stone.

The cost of a suitable computer installation is in the region of $5000, and although such a system would only be economically viable in the larger gem testing laboratory, or in an organisation already using a suitable computer system, the introduction of computing systems in such establishments is already making the advent of computer-aided gem identification more possible.

Figure 13.11, 13.12
An example of a 2-page gem profile as displayed on the video monitor



```
                   CHALCEDONY              (Page 1 of 2)
                   ~~~~~~~~~~

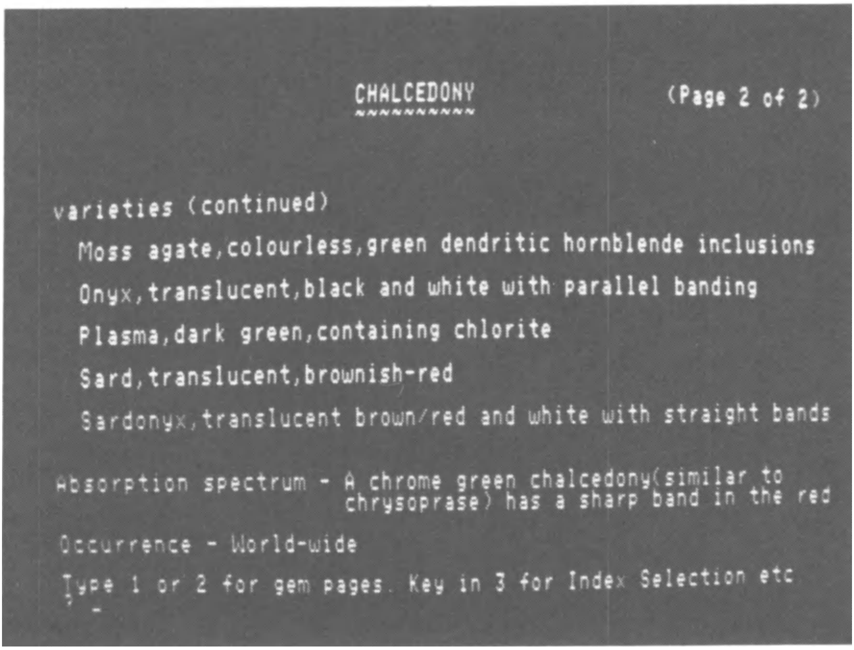
             A cryptocrystalline quartz

     R.I.(range)    D.R.    Disp.(max)   S.G.(range)   H.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
      1.53-1.54     C.C.       --         2.58-2.64     6.5

Chemical Composition        Xtal System   Optical Clarity
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
SiO                         Trigonal      Transparent
   2                                      to opaque

Varieties - Agate,translucent,all colourss,concentric bands
            Bloodstone,opaque,dark green with red jasper spots
            Chalcedony,translucent unbanded grey or blue
            Chrysoprase,translucent apple green
            Cornelian,translucent orange-red
            Fire agate,reddish iridescent in opaque chalcedony

 Type 1 or 2 for gem pages. Key in 3 for Index Selection etc
 ? -
```



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                   CHALCEDONY              (Page 2 of 2)
                   ~~~~~~~~~~


varieties (continued)

  Moss agate,colourless,green dendritic hornblende inclusions

  Onyx,translucent,black and white with parallel banding

  Plasma,dark green,containing chlorite

  Sard,translucent,brownish-red

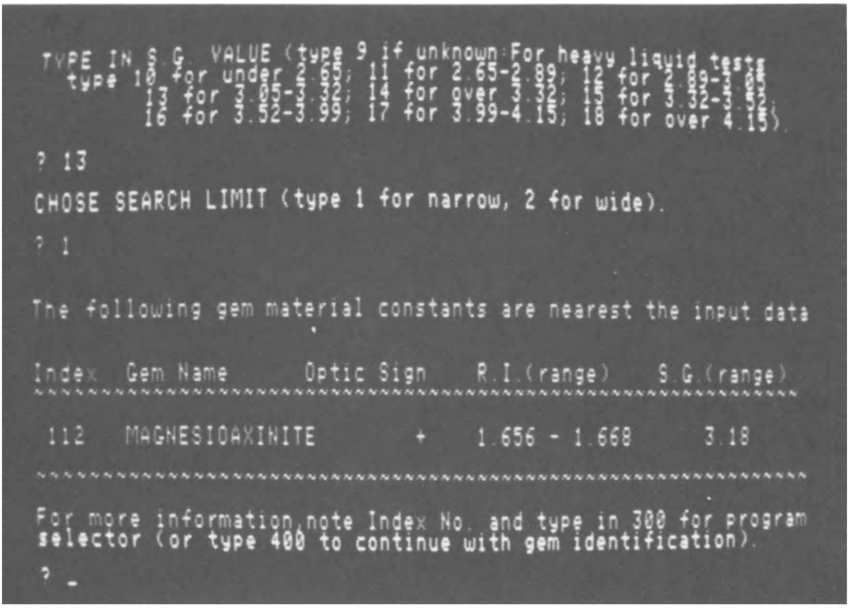
  Sardonyx,translucent brown/red and white with straight bands

Absorption spectrum - A chrome green chalcedony(similar to
                      chrysoprase) has a sharp band in the red

Occurrence - World-wide

Type 1 or 2 for gem pages. Key in 3 for Index Selection etc
? -
```

Figure 13.13, 13.14
Two examples where values of R.I., D.R., optic sign and S.G. have been keyed-in for a stone under test in response to the computer program's questions. This information has been compared by the computer with stored constants on over 200 gem minerals, and possible identifications are displayed when the input data matches these constants. Program options enable input values for R.I., D.R., optic sign and S.G. to be by-passed where these are not known.



```
TYPE IN S.G. VALUE (type 9 if unknown:For heavy liquid tests
  type 10 for under 2.65; 11 for 2.65-2.89; 12 for 2.89-3.05
          13 for 3.05-3.32; 14 for over 3.32; 15 for 3.32-3.52;
          16 for 3.52-3.99; 17 for 3.99-4.15; 18 for over 4.15).

? 13

CHOSE SEARCH LIMIT (type 1 for narrow, 2 for wide).

? 1

The following gem material constants are nearest the input data

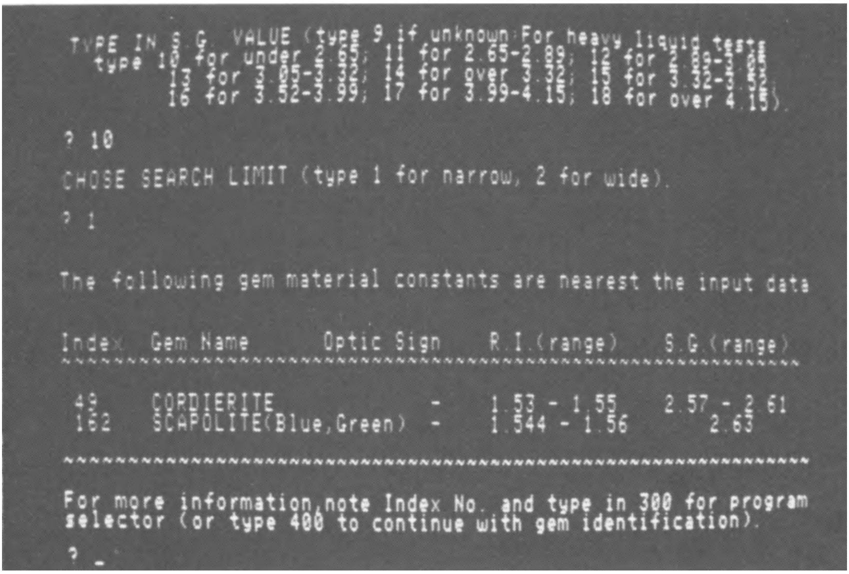
Index  Gem Name       Optic Sign    R.I.(range)     S.G.(range)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 112   MAGNESIOAXINITE         +     1.656 - 1.668      3.18

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

For more information,note Index No. and type in 300 for program
selector (or type 400 to continue with gem identification).

? _
```



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TYPE IN S.G. VALUE (type 9 if unknown:For heavy liquid tests
  type 10 for under 2.65; 11 for 2.65-2.89; 12 for 2.89-3.05
          13 for 3.05-3.32; 14 for over 3.32; 15 for 3.32-3.52;
          16 for 3.52-3.99; 17 for 3.99-4.15; 18 for over 4.15).

? 10

CHOSE SEARCH LIMIT (type 1 for narrow, 2 for wide).

? 1

The following gem material constants are nearest the input data

Index  Gem Name       Optic Sign    R.I.(range)     S.G.(range)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 49    CORDIERITE              -     1.53 - 1.55    2.57 - 2.61
 162   SCAPOLITE(Blue,Green)   -     1.544 - 1.56       2.63

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

For more information,note Index No. and type in 300 for program
selector (or type 400 to continue with gem identification).

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References

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6. Yu, R. M. and Healey, D., 'A phosphoroscope', *Journal of Gemmology* (October 1980)
7. Read, P. G., 'Computer-aided gem identification', *Journal of Gemmology* (October 1980)

14

Diamond Sorting and Grading

Equipment for the automatic sorting and sizing of rough gem diamonds. The grading of polished diamonds. Grading equipment. Grading standards. The weighing and weight estimation of diamonds. The identification of polished diamonds.

In the title of this chapter 'diamond grading' applies only to polished diamonds. The operations associated with the preparation of unpolished, or rough, diamonds for sale are described as 'diamond sorting', and it is these operations and allied equipment which will be described first.

De Beers Central Selling Organisation (CSO) in London receives 80% of the world's output of rough gem diamonds, and before these diamonds can be offered for sale to the accredited diamond buyers at the five-weekly 'sights', they have to be sorted into categories of shape, quality, colour and weight for valuation purposes. It is only when this has been done that proportional selections of these diamonds can be made up into 'parcels' to suit the needs of the individual buyers.

The sorting and sizing (or weighing) of diamonds are very labour-intensive operations, and as the sales of diamonds have increased over the years automatic aids[1] have been introduced.

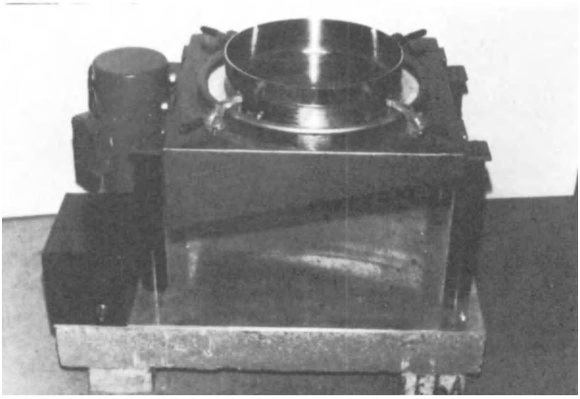
SIEVING

One of the first operations to be mechanised was sieving. The first stage in the sorting of diamonds is their division by sieving into two broad size groups called 'smalls' (less than 2.0 carats) and 'sizes' (2.0 carats upwards) so that these can be supplied to the appropriate departments. This initial division is then repeated to establish a series of smaller size groups.

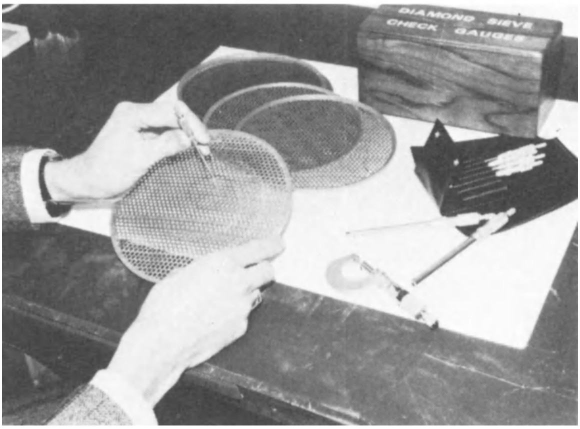
Sieving was originally carried out by hand, but as the sales of diamonds increased over the years this became a very arduous task. The automatic sieving equipment (*Figure 14.1*a) by Industrial Vibrators Ltd consists of a sieve plate clamping frame which is resiliently mounted via rubber blocks to a baseplate. An electric motor, bolted to the sieving frame, has adjustable eccentric weights fitted to its spindles, and as the motor runs, these weights impart a vibration to the sieving frame. The positions of the eccentric weights are adjusted to achieve the desired sieving motion.

Although sieving is not a very precise method of 'sizing' diamonds, it has the advantage of speed, and is sufficiently accurate for the initial subdivision, the majority of the diamonds being accurately weighed at the end of the sorting operations. Even so, it is still important that the holes in the individual sieve plates are manufactured to a close tolerance. The plates

Figure 14.1a
A vibratory sieving machine for rough diamonds. The sieve plate is secured under a 'hopper' section by four toggle clamps



14.1b
Sieve plates are checked for hole tolerances using a ball gauge and a micrometer



have a nominal sieving diameter of either 8 or 10 in. and are made from stainless steel. To achieve a consistent high accuracy, the holes are punched in the plates by machine, the hole tolerances being maintained to within ±0.001 in. Each sieve plate is carefully checked after manufacture, and at intervals during its life (*Figure 14.1b*).

COUNTING

The counting of diamonds, though not a sorting operation, is a necessary but time consuming process, and occurs at frequent intervals between the various sorting operations. To achieve the high standards of accuracy and reliability necessary in the counting of large batches of diamonds, the CSO designed their own electronic diamond counter (*Figure 14.2*). This consists of a vibratory bowl feeder which separates the diamonds into a single file and drops them, one at a time, through a detector.

Figure 14.2
A counter/batcher for rough diamonds. The output box is at the right-hand end of the counter

The detector consists of an infra-red 'light-curtain' in which a fine beam of infra-red light is reflected between two parallel mirrors to form a lattice or 'curtain' of rays, the final beam being detected by a photodiode. As the light beam is reflected from each mirror surface, it suffers attenuation, and the angle of the mirrors is adjusted to increase the number of reflections until there is just sufficient light left to operate the photodiode.

Two such light curtains are built into the detector, the first one counting the diamonds and the second one checking this count. If for any reason there is a discrepancy between the two sections of the detector, an error circuit is operated and the vibratory bowl feeder is switched off. A batching facility is provided which enables a pre-selected number of diamonds to be counted.

SORTING

The sorting of diamonds for colour is another area in which automation has been introduced. Because of the large differences in price that exist between the six colour grades[2] in the larger diamonds, these are still sorted by hand, the economics of the operation making it possible to spend time and expertise on each stone. The stones are sorted for colour in north daylight, and until a few years ago the sorters had only a short working day during the winter months. However, fluorescent lamps which simulate the north light have now made it possible to continue sorting under artificial daylight. The smaller diamonds are sorted into three basic colour grades[3] by means of a high-speed Gunson colour sorter.

The Gunson diamond colour sorter has evolved from an early machine which was originally developed to separate discoloured peas from green ones. A more recent version, model 426D (*Figure 14.3*), uses a hopper-fed vibrator which dispenses a single-line stream of diamonds into the channel of a continuously running V belt. The speed of the belt is set so that the diamonds landing on it are separated from each other. At the output end of

Figure 14.3
The Gunson twin-channel diamond colour sorter (Gunson's Sortex)

the belt, the diamonds fall through a sensor box which contains quartz halogen lamps and photomultipliers. The colour of each diamond is detected by the photomultipliers against background colour plates which can be changed to suit the appropriate colour sort. Signals from the photomultipliers are fed to an electronics control unit which can be adjusted to produce an eject signal whenever a diamond having a lower colour grade than the preset limit passes through the sensor box.

Diamonds having an acceptable colour pass over a divider plate into an 'accept' channel. Diamonds having a poorer colour produce an eject signal from the electronics unit which is used to operate a pneumatic valve. This valve directs a very short precisely-timed blast of compressed air at the diamond as it emerges from the sensor box, and deflects it under the divider plate into a 'reject' channel. The sorting rate is in the region of 20–30 diamonds per second, and each machine is fitted with two completely independent sorting channels. With this speed of sorting and with several such machines, it is therefore possible to put a batch of diamonds through the machine several times and produce a progressively more accurate colour sort.

An elementary shape sorter (*Figure 14.4*), which is used to remove 'flats' (thin, often triangular-shaped, diamonds) from the more 'blocky' shapes, is made by Hauni South Manufacturing (Pty) Ltd., of Cape Town. This uses two steel contra-rotating rolls, the gap between the rolls being set by micrometer adjustments at each end. Diamonds are fed by means of a vibratory feeder to the top end of the rolls, which are angled so that the diamonds progress down the inclined groove formed between the rolls.

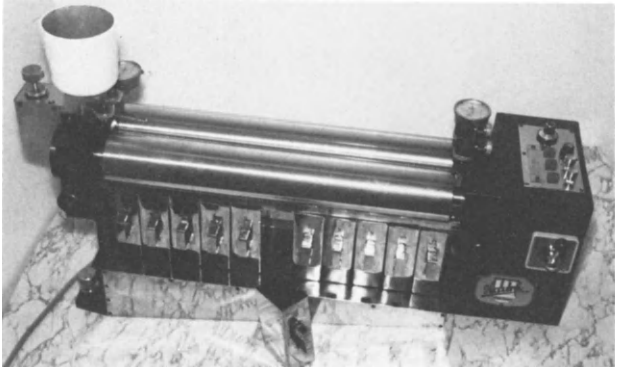


Figure 14.4
The Hauni roller sorter for separating diamonds by minimum diameter or thickness

If the gap between the rolls is set so that it is small at the top end and larger at the bottom end, the diamonds will pass down the slope until they reach a point where the gap is wide enough to allow them to drop through. A series of output boxes are placed under the rolls and enable diamonds of varying thickness or diameter to be separated out.

Separating diamonds into categories of shape[4] and quality[5] (i.e. freedom from internal features such as inclusions and flaws) is still very much the province of the skilled diamond sorter, although no doubt both of these tasks will one day be aided by automatic devices, particularly at the very small end of the size range. Until then, diamond sorters will continue to use head loupes and illuminated opal glass panels in the surface of the bench to sort diamonds down to sizes of 40 per carat.

Weighing

One other operation which the CSO has successfully automated is the weighing of diamonds and the sizing of them into weight categories[1]. When the diamonds which are being prepared for a 'sight' have been sorted for shape, quality and colour, each stone within these categories has to be weighed individually and placed into the appropriate weight category. These weight categories are divided into one carat intervals, i.e. from 1.81 to 2.80, 2.81 to 3.80 and so on up to 14.80 carats. Diamonds below 1.81 carats are sub-divided into smaller intervals, depending on their type, and diamonds above 14.80 carats are individually hand weighed.

Figure 14.5
An automatic weigher for rough diamonds. On the bench is the feeder/weigher unit with the two rows of plastic output boxes. After weighing, diamonds are guided by rotary solenoid flaps into the appropriate box. Under the bench is a drawer unit containing the electronic circuits

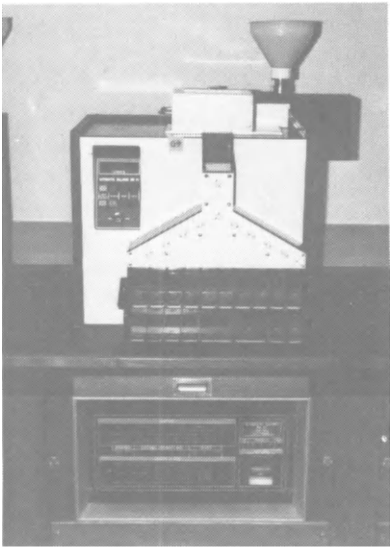
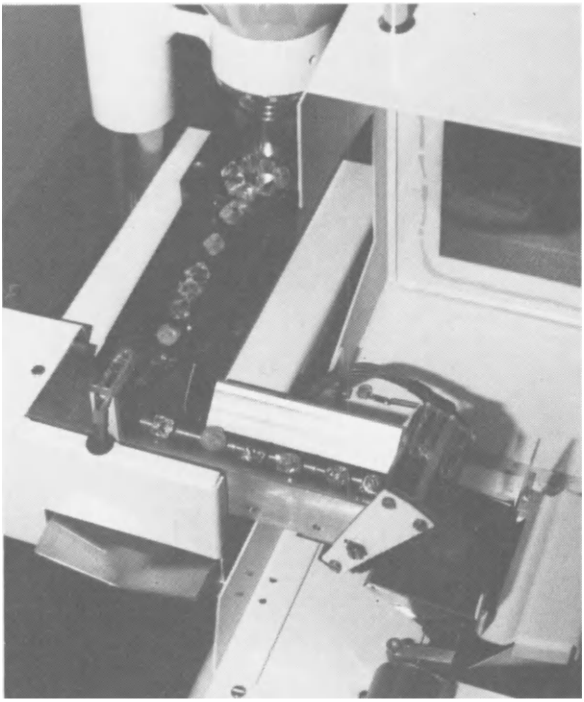


Figure 14.6
The hybrid vibratory/roller feeder on the automatic diamond weigher deposits diamonds one at a time on the pan of the electronic balance. The weighed diamond is then ejected and gravity-fed to the appropriate output box



The automatic weighers can either operate independently, when they use an internal sizing programme to place the weighed diamond in the appropriate size box, or they can work under the control of computers which record the weighing data and process it (*Figure 14.5*).

Each machine can size up to 3000 carats at one loading, and is capable of weighing each diamond in the batch to an accuracy of ±0.005 carats at the rate of one every three seconds. The 'heart' of the machine consists of a Mettler KM102 electronic tablet balance, around which the CSO have designed their own feeding and sorting mechanisms and control circuits (*Figure 14.6*).

THE GRADING OF POLISHED DIAMONDS

We now move from the world of rough gem diamonds to that of the polished end product. Polished diamonds are graded to what is known as the 'Four C's' of colour, clarity, carat and cut. Over the years, various nationally accepted standards for the grading of diamonds for colour, clarity (or purity) and cut (or proportion) have been established.

Although the diamond dealer may evaluate a given diamond directly in terms of its buying or selling price, descriptive and acceptable grading classifications are necessary for the international trading in polished diamonds. For many years, the various national grading standards and descriptions tended to increase rather than reduce the confusion in the communication of diamond classification on an international level.

The establishment of a Diamond Commission (now renamed the Diamond and Coloured Stone Commission) by the international jewellery organisation CIBJO[6] has resulted in a common set of of colour and clarity grades being established in twelve countries. The CIBJO grades, and their relationship to the various national grades, will be described in detail later in this chapter.

The following description of the grading of polished diamonds for colour, clarity and cut is intended only as an introduction to the associated equipment. For a more detailed appraisal of grading techniques, reference should be made to Mr. E.Bruton's book 'Diamonds' (NAG Press Ltd, 2nd edn, 1981) and Varena Pagel-Theisen's 'Diamond grading ABC' (Rubin, 7th edn, 1980).

Colour grading

For the colour grading of polished diamonds, two essentials are required. One of these is the correct illumination, and traditionally this is a neutral (i.e. white) north light (or, in the southern hemisphere, such as South Africa, a south light). The second requirement is for a colourless background so that the eye is not biased by its attempts to compensate for surrounding colours (e.g. the eye will eventually adapt itself to seeing a slightly tinted background as white).

The colour grading of a polished diamond depends upon the ability of the grader to both see and appraise the body colour of the stone. As a brilliant cut diamond is fashioned so that as much as possible of the light entering its crown facets is reflected back, it follows that it can be quite difficult to look into the stone and form an appreciation of its body colour.

Experience has shown that one of the best methods of appraising a diamond's colour is to lay it, table facet down, in the crease of a piece of folded white paper, or card, and to inspect the diamond through the side of the pavilion.

Until fairly recently, no attempt was made to continue with the colour grading of diamonds once the natural daylight had faded. These days, there are several colour corrected fluorescent lamps available which enable the colour grading of diamonds to be continued successfully under artificial daylight conditions. In fact, having spent many hours in the colour sorting/grading of both rough and polished diamonds, the writer believes that once experience has been gained in the use of a colour-corrected lamp, the most consistent results are achieved by using the same light source at all times.

The colour grading of diamonds is greatly assisted by the use of a master set of comparison stones. These stones should be correctly proportioned, but need not be flawless, although any flaws present should not be visible without the aid of a loupe, and should not affect the colour or transparency of the stone. For the grading of diamonds up to half a carat, the master stones should not be smaller than 20 points (0.2 carat).

A set of diamond masterstones, having a minimum weight of around 20–25 points can be expensive ($2000 for 5 stones E to I, Rubin). An alternative is to use a set of cubic zirconia stones ($400 for 5 stones D to H, Rubin; $455 for 6 stones D to I or E to J, GfD). Because the yellow tints of simulants such as cubic zirconia are caused by absorption characteristics which differ from diamond's 415.5 nm system, possible metameric effects make it important that they are used under the correct 5000K lighting conditions (i.e. the light under which they were originally graded).

While most diamond grading laboratories use master stones, use is also made of electronic photometers to measure the colour of diamonds. A description of several of these commercial instruments is given in Chapter 4, which deals in a general way with the appearance of gemstones in terms of their colour.

Another good argument for the use of a 'daylight' type diamond grading lamp is that the 'north' light varies considerably in the different hemispheres. There is also a marked difference in the colour balance between daylight in the early morning, light from an overcast sky, and that from a clear north sky. These variables have been clearly illustrated in a graph contained in an article on diamond colour measurement by Mr. M. Eickhorst[7].

A large proportion of diamonds fluoresce under ultra-violet light, and because daylight (and 'daylight' fluorescent lamps) contains a proportion of ultra-violet rays, such stones can appear to be 'whiter' than they actually are because of their blue fluorescence. For this reason, most lamps have a diffusing cover over their fluorescent tubes which absorbs ultra-violet rays, and, in addition, have a separate LW ultra-violet lamp which can be used independently to check diamonds for fluorescence.

COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

DIAMOND GRADING LAMPS

The following paragraphs describe a selection of lamps and accessories designed specially for the colour grading of diamonds.

DiamondLite (GIA/Gem Instruments Corp) (*Figure 14.7*)

This unit not only provides a diffused illumination similar to that of north daylight, but also encloses the area adjacent to the test position with a neutral white background.

The diamonds to be graded can either be placed on the large display pad, together with comparison stones, or if a more subdued lighting is required, they can be placed in the translucent adjustable tray and inserted in the recessed compartment at the top of the unit. This allows the light to be filtered through the translucent tray before entering the diamond.

The unit is fitted with a separately-controlled LW ultra-violet light source to test diamonds for fluorescence. ($285).

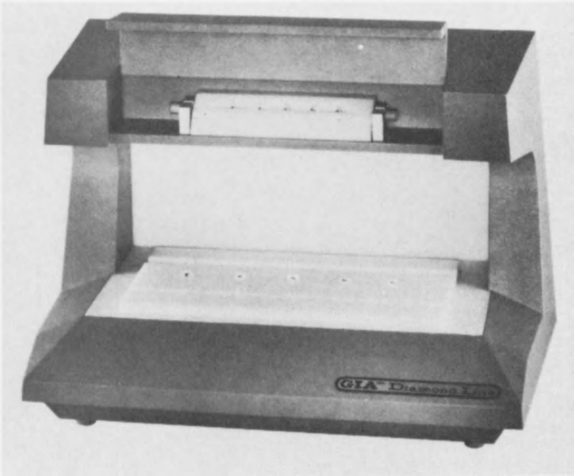


Figure 14.7
The GIA 'DiamondLite', provides a daylight illumination and a neutral background for the colour grading of diamonds (Gem Instruments Corporation)

Colour grader (Gem Instruments Corp)

This is an adjustable translucent white diamond grading tray for use with the GIA Gemolite microscope and Diamond Grader microscope. ($84).

Overhead light source (Gem Instruments Corp)

An incident light source designed for general and diamond grading use with the GIA Gemolite microscopes and the Diamond Grader microscope. It is fitted with two 4 W fluorescent tubes which are covered with an opalescent diffuser. ($90).

Daylight lamp, B-Type (GAAJ)

A five-sided open-fronted cabinet with two 6 W colour corrected fluorescent tubes designed to simulate north light and centered on a wavelength of 480 nm (4,800 Å). The tubes are mounted in the top of the cabinet and are covered with a diffusing plate of translucent acrylic sheet.

An independently controlled LW ultra-violet black light is also fitted to check diamonds for fluorescence. The unit is designed for 110 V, 50/60 Hz operation, and requires a step-down transformer for use on 240 V.

Daylight lamp stand, S-Type (GAAJ)

This uses two 6 W fluorescent tubes designed to simulate north light, with their emission entered on a wavelength of 480 nm (4800 Å). The tubes are covered with a translucent white plate.

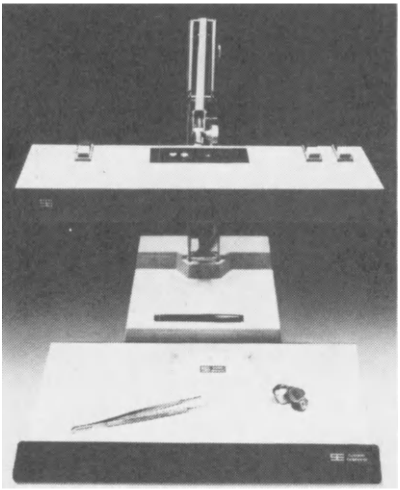


Figure 14.8
The Dialite diamond grading lamp (Eickhorst)

Dialite desk lamp DUV-S (Eickhorst) (*Figure 14.8*)

This unit employs double spring-counterpoised arms enabling it to be adjusted to a variety of heights and positions. Two 8 W daylight fluorescent tubes (selected to comply with the 5000 K CIBJO and ISO colour standard) are fitted in the lamp head and these can be used together or singly. The head also carries a LW ultra-violet lamp, and this is fitted so that it shines upwards. To test a diamond for fluorescence, the lamp head is moved to a position so that its top is level with the eyes. The diamond is then placed on top of the U-V lamp and viewed in line with the plane of the girdle. This method of viewing ensures that the eyes are protected from the U-V rays, and enables a fluorescing stone to be seen with best contrast. ($265).

D light stand (Nikon Hoseki-Kizai Co., Ltd.)

This is a desk stand using two 6 W daylight lamps having a colour temperature of 4800 K. ($130).

Colorscope (Eickhorst) (*Figure 14.9*)

This is a small open-sided grading unit using two 6 W daylight tubes with a colour temperature of 5500 K. ($149); Accessories include a 2.5× rectangular lens ($24) and a LW U-V lamp unit ($86).

Magno-Colorscope (Eickhorst)

This is an open-front colour grading cabinet fitted with two 8 W daylight 5500 K tubes and a pivoting 2.5× rectangular magnifying lens. ($250).

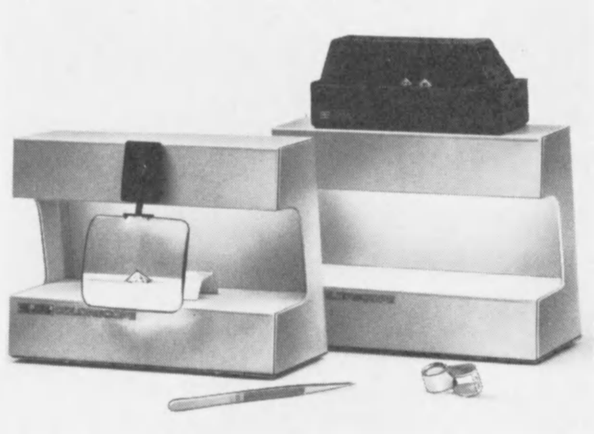
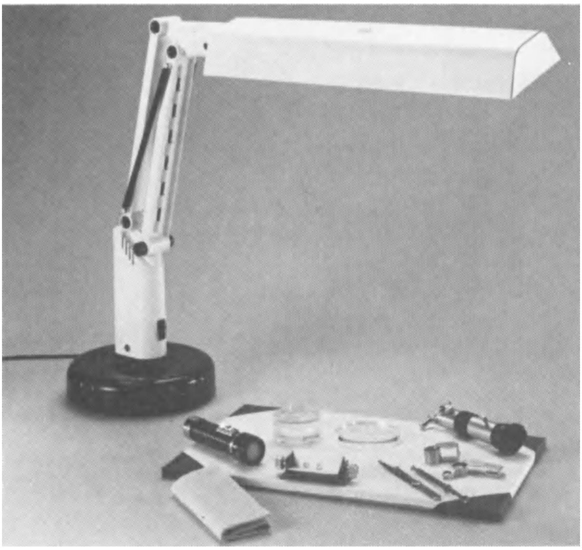


Figure 14.9
The Colorscope is a compact and portable diamond grading cabinet. The units shown here are fitted with lens and U-V cabinet accessories (Eickhorst)

Figure 14.10
The AL25 diamond grading lamp (Krüss)



Coldlight analysis lamp AL25 (Krüss) (*Figure 14.10*)

This is a twin 15 W counterpoise table lamp of Scandinavian design having a colour temperature of 5500 K. It can be supplied in a black or white finish with a desk stand or a table clamp. ($134).

Lucifer (Rubin)

This is similar to the Krüss AL25. Available in black, white, red or brown, with a desk stand or table clamp. ($93).

CLARITY GRADING OF POLISHED DIAMONDS

The colour grading lamps just described are, of course, equally useful as sources of illumination when grading polished diamonds for clarity or purity (i.e. inspecting them for inclusions and flaws).

Apart from adequate illumination, the only other equipment necessary (assuming that the diamond has first been carefully cleaned) is a 10× hand loupe, or a microscope with a 10× magnification, this being the standard magnification specified for the clarity grading of diamonds.

The best method of illuminating a diamond for clarity grading is to position it against the edge of the lamp housing so that the light enters the side of the stone through the girdle, thus simulating dark-field illumination. If the diamond is then examined with a 10× loupe, any inclusions, etc, will be clearly visible against the dark background of the diamond.

The influence of the size, position and number of inclusions or flaws on the clarity grade is discussed later in this chapter when the various grading standards are compared.

EQUIPMENT FOR PROPORTION GRADING

There are several so-called ideal cuts or sets of dimensional proportions and facet angles for the round brilliant-cut diamond (two of these are shown in *Figure 14.11* in which the various facets are also identified). The object of an ideal cut is to reflect back as high a proportion of light entering the table facets as possible. The 58-facet brilliant cut has therefore evolved to its present shape through the appreciation of the optical geometry necessary for the total internal reflection of light rays entering the table facets.

For a poor colour and low quality rough diamond, the polisher will probably modify the angles and proportions of the ideal cut so as to end up with as much weight as possible in the finished diamond. The reason for this is that with a poor colour and low quality diamond the loss of value caused by a poor cut is more than compensated for by the 'yield' or final

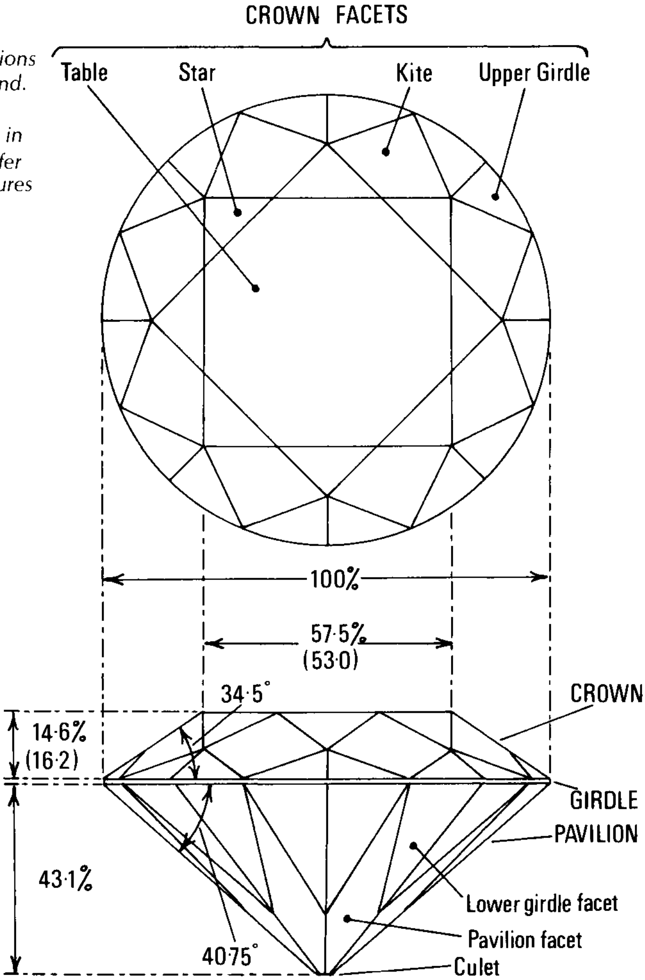


Figure 14.11
The Scan. D.N. proportions for a brilliant cut diamond. The Tolkowsky (USA) proportions are shown in brackets where they differ from the Scan. D.N. figures

weight. However, for a top colour and quality rough diamond, it is far more important economically for the cut to be as near perfect as possible, and in this case the polisher will adhere strictly to the ideal angles and proportions.

The variety of poor cuts or proportions that may be met with in a diamond include a sloping table facet, out of centre culet, overdepth pavilion, shallow pavilion, thin crown, extra facet(s), asymmetrical cut and incorrect angles.

If the angle between the pavilion and the girdle is too large (above 41°), the pavilion will become overdeep. This will result in poor bezel reflections and little or no fire. If, however, the angle of the pavilion is too shallow, this will result in a blank area in the centre of the stone. This blank area is the reflection of the girdle, and is often called a 'fish eye'.

If a diamond has been correctly faceted with the star facets reaching half-way down the side of the crown, it is a simple matter to check if the width of the table facet is in the correct proportion to the diameter of the girdle. If the two superimposed squares (offset to each other by 45°) which are formed by the table and star facets appear to have straight sides when viewed from above, then the table width is 60% of the girdle diameter (Scan. D. N. specifies 57.5%). If the table is larger than this, the squares will have a convex 'pincushion' appearance, and if the table is smaller, the sides of the squares will be concave.

There are several commercial instruments which enable the proportions and facet angles of a brilliant cut diamond to be checked. Five of these instruments will now be described.

The ProportionScope (Gem Instruments Corp) (*Figure 14.12*)

This is essentially a back-projection shadowgraph type instrument which projects the shadow profile of the diamond onto a translucent screen. The screen is overprinted with horizontal and vertical scales which enable the proportions and the crown/pavilion facet angles to be checked, together with the thickness of the girdle and the culet diameter.

The diamond holder has two threaded rods which are screwed inwards to grip the diamond between the culet and the centre of the table facet. The holder has a magnetic base and can be easily moved to centre the diamond in the projection beam. Two screens are provided, one for stones from 0.18 to 1.3 carats, and the other for 1.21 to 8 carat stones. The unit is for operation from 110 V, 60 Hz. A 220 V, 50 Hz version is available. ($750).

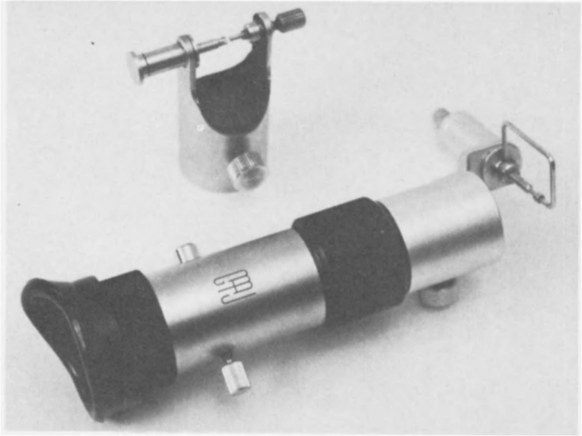
Diamond proportion analyzer (Gem Instruments Corp)

This uses the same magnetic-base diamond holder as the Proportionscope, but is intended for use with zoom-type microscopes similar to the Custom Mk V Gemolites.

The analyzer kit includes a 15× Gemolite eyepiece fitted with a diamond proportion graticule. The zoom facility of the microscope enables the profile image of the diamond to be matched to the graticule outline. ($145).

Figure 14.12
The GIA ProportionScope for checking the dimensions and angles of the crown and pavilion facets (Gem Instruments Corporation)

Figure 14.13
The Diamond Proportion Handscope (Topcon)



Diamond proportion handscope (Topcon/GAAJ/Krüss/Rubin) (*Figure 14.13*)

This instrument comprises a portable zoom 'hand microscope' fitted with a diamond proportion graticule and supplied with two stone holders (one of which can be used to rotate the stone to check for symmetry). The eyepiece is fitted with an adjusting ring to bring the graticule into focus (the graticule conforms to the European Scan. D.N. proportions). A small knurled metal knob next to the eyepiece enables the graticule to be aligned horizontally with the profile image of the diamond. The large black adjusting ring towards the rear of the Handscope is the zoom adjustment (with a range of 2:1) which enables the diamond image to be matched in size to the outline of the graticule.

The image of the diamond is focused by slackening the knurled clamping screw on the barrel of the holder, and sliding the holder back and forth for optimum focus. The stone holder is provided with an adjustment for setting the vertical position of the diamond relative to the graticule.

The total magnification range of the instrument is 10.6× to 21.2×, and this enables diamonds from 25 points (0.25 carat) to 2 carats to be inspected. The graticule is graduated in 1% steps, and the instrument is designed for use with external illumination. ($536).

The SP1U Proportionscope (Hans-Günter Schneider)

This unit consists of an objective, stoneholder, adjustable stand and a plexiglass screen for millimetre-squared sheet. ($590).

The Proscope (Gemphot/Krüss) *(Figure 14.14)*

This is a compact shadowgraph instrument in which the appropriate graticule can be inserted in the viewing window for the estimation of a diamond's facet angles and proportions. A quartz halogen lamp is used as the light source and produces a sharply contrasted image easily visible in normal room lighting. The diamond is held in a spring holder and can be rotated for all-round viewing. ($786).

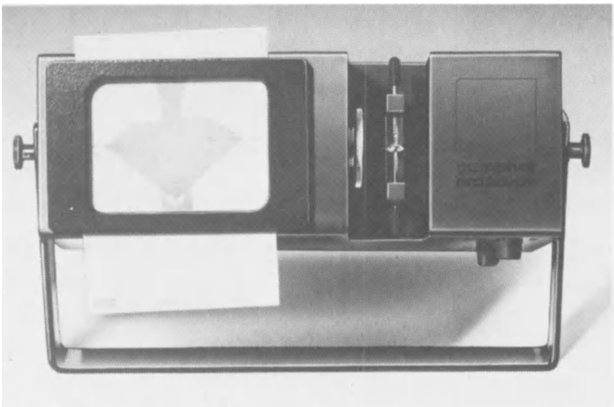


Figure 14.14
The Proscope diamond proportion grader (Gemphot)

GRADING STANDARDS

Table 14.1 shows the relationships between the various national colour grading systems and the international CIBJO[6] grades. The original top three grades in the CIBJO system (Exceptional White, Rare White and White) have now been subdivided into five grades, corresponding with the GIA grades, D, E, F. G. H.

All of the grades shown in the table are based on carefully chosen sets of master stones. With the exception of CIBJO and GIA grades, master stones correspond to the centre colour of each grade. With CIBJO and GIA the master stones are chosen to correspond to the lower limit of each grade, and this makes it much easier to decide to which grade a borderline stone belongs. For the eight CIBJO grades, sets of seven master stones were chosen and supplied to the various grading laboratories.

Table 14.2 shows the relationship between the various national clarity grading systems and the international CIBJO grades.

Table 14.3 explains briefly the range of inclusions or flaws associated with each clarity grade.

Table 14.1
Colour grading standards for polished diamonds

UK	*German RAL Scan. DN* (0.5 carats upwards)	*Scan. DN* (under 0.5 carats)	*GIA*	*AGS*	*CIBJO*
Finest White	River	Rarest White	D	0	Exceptional White +
			E	1	Exceptional White
Fine White	Top Wesselton	Rare White	F	2	Rare White +
			G		Rare White
White	Wesselton	White	H	3	White
Commercial White	Top Crystal	Slightly Tinted White	I	4	Slightly Tinted White
Top Silver Cape	Crystal		J	5	
Silver Cape	Top Cape	Tinted White	K		Tinted White
			L	6	
Light Cape	Cape	Slightly Yellowish	M		Tinted Colour
			N	7	
Cape	Light Yellow	Yellowish	O		
			P	8	
			Q		
			R	9–10	
Dark Cape	Yellow	Yellow	S–Z		

Table 14.2

UK	*RAL*	*Scan. D.N.*	*GIA*	*Belgium*	*CIBJO*
Flawless	IF	FL IF	FL	IF	Loupe-clean
VVS	VVS	VVSI 1 VVSI 2	VVSI 1 VVSI 2	VVS	VVS 1 VVS 2
VS	VS	VSI 1 VSI 2	VSI 1 VSI 2	VS	VS 1 VS 2
SI	SI	SI 1 SI 2	SI 1 SI 2	SI	SI
1st PK	PK 1	PK 1	I 1		PI
2nd PK	PK 2	PK 2	I 2		PII
3rd PK	PK 3	PK 3	I 3		PIII
Spotted					
Heavily Spotted					
Rejection					

Table 14.3
Clarity grading standard

CIBJO Clarity grading (10× magnification)	
Loupe-clean	A diamond is classified as loupe-clean if it is completely transparent and free from visible inclusions.
VVS (VVS1, VVS2)	Very, very small inclusions which are hard to find with a 10× loupe.
VS (VS1, VS2)	Very small inclusion(s) which can just be found with a 10× loupe.
SI	Small inclusion(s) easy to find with a 10× loupe, but not seen with the unaided eye through the crown facets.
PI	Inclusion(s) immediately evident with a 10× loupe, but difficult to find with the unaided eye through the crown facets. Not impairing brilliancy.
PII	Large and/or numerous inclusion(s), easily visible to the unaided eye through the crown facets, and which slightly reduce the brilliancy of the diamond.
PIII	Large and/or numerous inclusion(s), very easily seen with the unaided eye through the crown facets, and which reduce the brilliancy of the diamond.

Note: Sub-grades VVS1, VVS2, VS1 and VS2 are only used for stones of 0.47 carat and larger.

THE WEIGHING AND WEIGHT ESTIMATION OF DIAMONDS

Gemstones, including diamonds, are traditionally weighed in carats. The carat weight standard has a long history, being originally derived from the seed of the middle-eastern Carob tree. These seeds when dried have the unusual quality of being almost identical to each other in weight and were originally used as very convenient units of weight in the pearl trade.

As commerce in pearls and gemstones spread across the globe, the carob seed, or carat, was adopted by many countries who modified its weight so that it was related to their own national weight units. This resulted in a carat weight which varied in its mass from country to country. Eventually, early in this century, a common standard carat weight, called the metric carat, was agreed upon by the various countries. There are exactly five metric carats to the gram.

It is relevant to mention at this point that in line with the recommendation of the Conférence Générale de Poids et Mesures, and the change to SI units, the term 'weight' (when it refers to a quantity) should preferably be replaced by 'mass', a coherent unit independent of gravity.

There are many designs and types of commercial carat balances for the weighing of gemstones, including both mechanical and electronic, top pan and analytical (including the twin-pan beam balance). A typical small mechanical top pan unit by Haigis is shown in *Figure 14.15*. This has a weighing range of 100 carats in 10 carat steps, the weights being contained internally and being brought into operation by the range control. The scale is graduated in 0.01 carat steps. Accuracy is ±0.002 carat, and the balance is magnetically damped. A transparent cover protects the weigh-

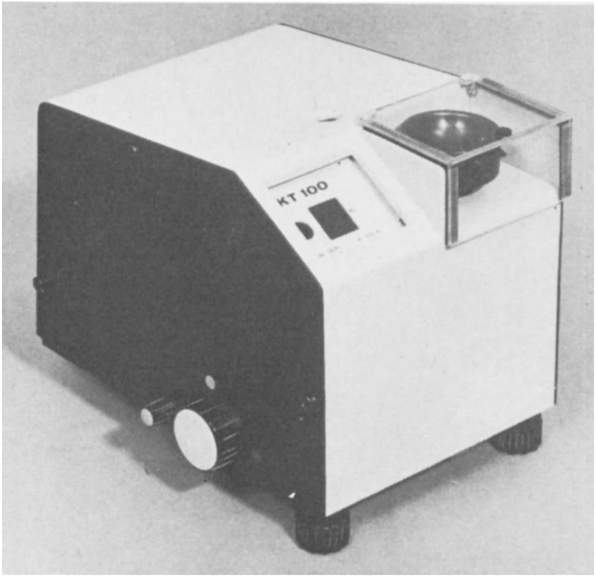
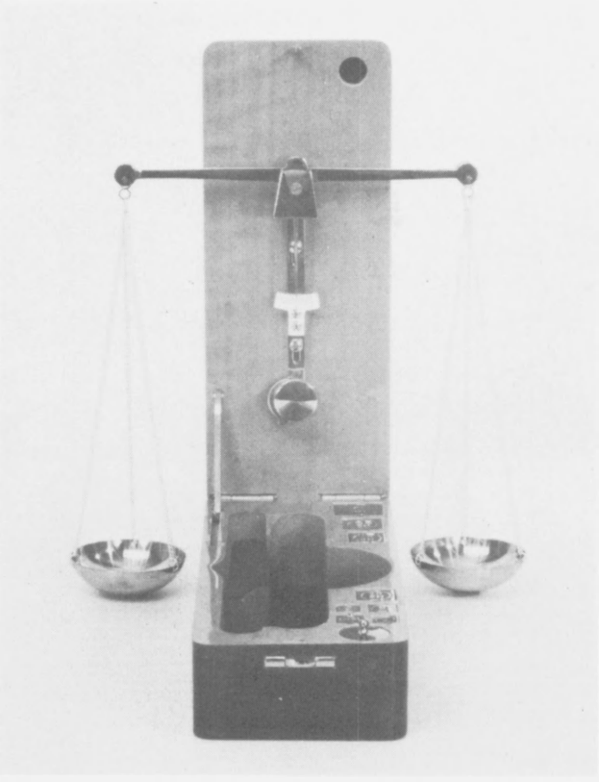


Figure 14.15
A typical top pan diamond balance (Haigis)

Figure 14.16
An analytical type mechanical carat balance (Bosch)

Figure 14.17
A portable diamond beam balance (Haigis)



pan from air currents when in use. ($936). The Bosch S2000 (*Figure 14.16*) is an example of a mechanical carat balance of the analytical type. It has a weighing range of 200 carats and an accuracy of ±0.001 carat. ($1196). This and other leading balances are available in the UK from European Instruments.

In contrast to the modern top pan balance is the small portable Haigis balance which is shown in *Figure 14.17*. This is a simple, but sensitive, undamped beam balance, and has the virtue of folding away neatly into its box, together with the weights. ($165 for 25 carat capacity to $230 for 250 carat capacity). With a 10× hand loupe, tweezers and a ring mounted comparison stone, the diamond dealer can use this portable fold-away balance to transact business almost anywhere.

Electronic balances range from the analytical top-loading Sartorius model 1207MP2 ($1840, with an 80 gram capacity and 0.1 mg sensitivity) as illustrated in *Figure 14.18*, to the Mettler PB300C ($2065, with a 300 carat capacity and a 0.001 carat sensitivity). Mettler balances are available from Gallenkamp, European Instruments, Rubin and the Gem Instruments Corporation. Japanese electronic top-pan carat balances made by Shimadzu and Shinko are available from Nihon Hoseki-Kizai Co. Ltd.

Earlier types of electronic balance retained some of the mechanical features of the mechanical beam balance, and replaced the substitutional weights with a magnetic force-balance system. When an object was

Figure 14.18
An analytical electronic balance (Sartorius)

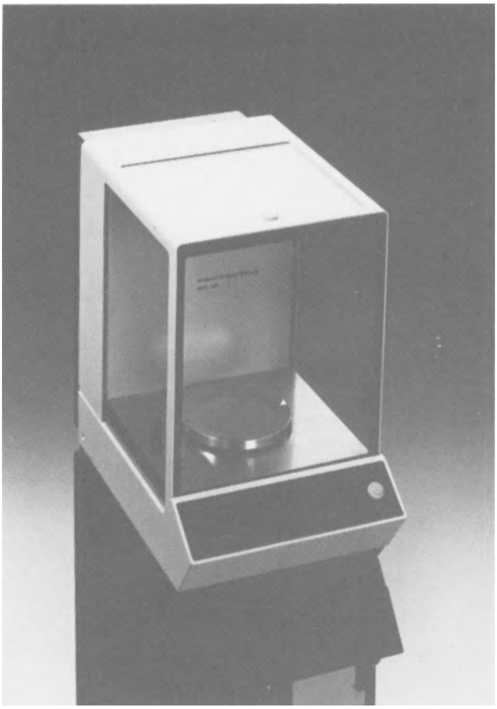
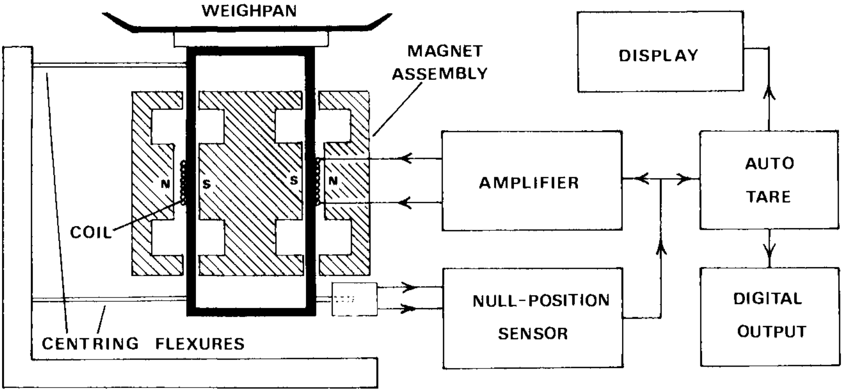


Figure 14.19
Sketch showing the main components in a pivotless electronic balance



placed on the weighpan, an out-of-balance detector or null-position sensor adjusted the current in a counterbalance coil to restore the beam to equilibrium via an amplifier. This in-balance current was then measured and displayed digitally as a weight reading. The latest electronic balances dispense with pivots and beams entirely, and suspend the weighpan/ force-coil assembly from centring fixtures in a strong magnetic field (*Figure 14.19*). The advent of the microprocessor has made it possible to incorporate such features as weight-unit change (i.e. gram to carat), automatic tare and weight integration (averaging of several successive weighings to guard against vibrational errors).

Carat balances are all very well for the weighing of unmounted stones, but if the gem is mounted in a piece of jewellery, other methods must be used to arrive at its weight.

The simplest alternative method of estimating the weight of a stone is by means of a hole gauge. This consists of a flat plate of plastic or metal which has punched in it a series of holes, whose diameters correspond with that of round brilliant cut diamonds of various weights. The hole gauge is designed for diamonds having ideal proportions, and allowance has to be made for shallow or over-deep stones. The weight of other brilliant cut gemstones can also be estimated with the aid of the hole gauge, allowance being made for the S.G. of the gemstone as compared with that for diamond, and for any obvious departure from the ideal diamond cut.

Rather more accurate weight assessment can be made by using a Moe gauge, which is basically an outer-diameter caliper gauge. Using this gauge, both the depth between culet and table facets, and the girdle diameter can be measured. These measurements can then be referred to a table supplied with the gauge, and the weight arrived at. Moe gauges are available from Rubin, Gemological Instruments Ltd, and Gem Instruments Corporation ($17.50 to $24).

One of the more accurate means of estimating a mounted gemstone's weight is to use the Leveridge gauge (*Figure 14.20*). This is quite an

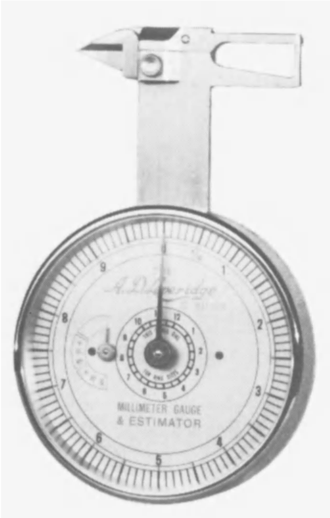


Figure 14.20
The Leveridge gauge for estimating the weight of mounted diamonds (Gemmological Instruments Ltd/Gem Instruments Corporation/Rubin)

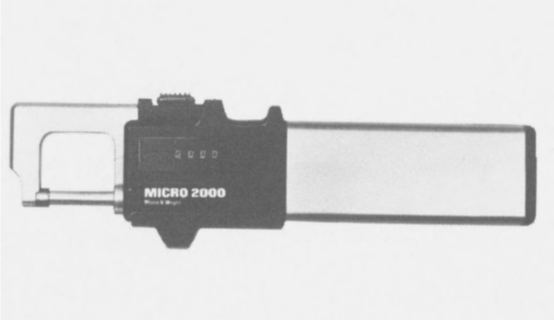


Figure 14.21
The Moore and Wright electronic micrometer for measuring diamond dimensions (Neill Tools Ltd)

expensive instrument, but enables precise measurements of both depth and girdle diameter to be made. Two gauge arms enable external and contact point measurement to be taken, and the girdle diameter can be measured conveniently by laying the diamond, table facet down, between two gauge steps. As with the Moe gauge, tables are provided and give diamond weights for a variety of different cuts. ($125 to $215). A similar dial gauge, the Diamond Scale, is available from Nikon Hoseki-Kizai Ltd. ($190).

An even more accurate and repeatable measure of a stone's dimensions can be obtained with the Moore and Wright Micro 2000 electronic micrometer which is available from Rubin complete with box and charger. ($379), and from the UK agents Neill Tools Ltd. (*Figure 14.21*).

In contrast to the large automatic sieving equipments used by De Beers CSO, much smaller hand-operated sieves are in frequent use by diamond dealers, to roughly size brilliant cut diamonds by diameter. These sieves consist of metal barrels into which fit inter-changeable sieve plates. The barrels nest together to form a multiple sieve, allowing several different

Figure 14.22
A nest of sieve plates for sizing polished diamonds (Haigis)

diameter sizes to be separated out in one operation. A typical jeweller's 2-sieve stack is shown in *Figure 14.22*. ($356 for a 20 sieve set, $584 for a 40 sieve set). Single-sieve containers are also available ($177 for 20 sieves, $308 for 40 sieves).

THE IDENTIFICATION OF POLISHED DIAMONDS

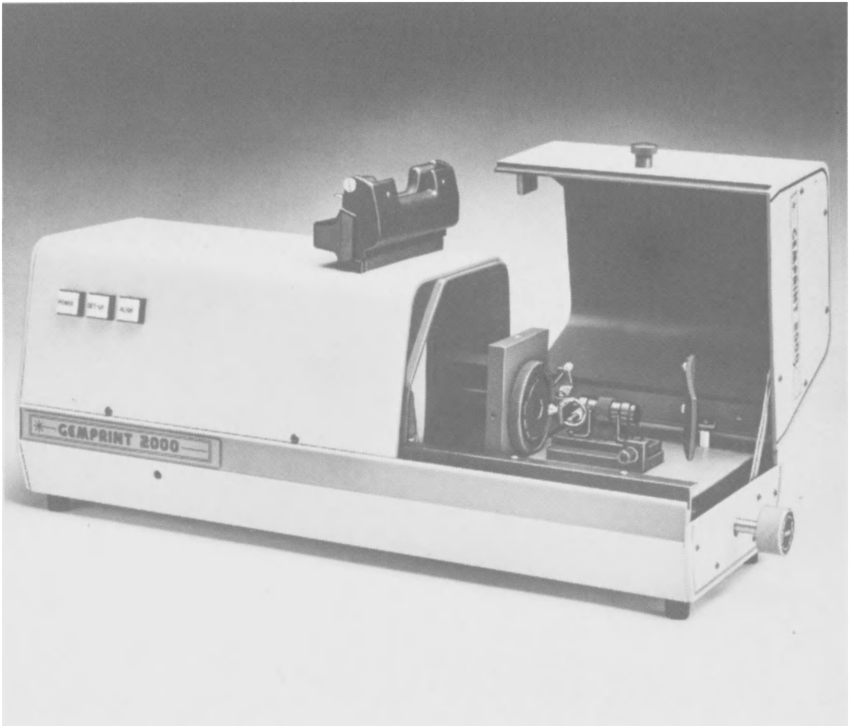
One of the problems with the buying and selling of diamonds is that the buyer often requires a certificate with his purchase (particularly if it is an unmounted stone bought for investment purposes). Such certificates are issued by many organisations and grading laboratories, and vary from a simple authenticated statement of the diamond's colour and clarity grading and weight, to a dossier of sophisticated tests and measurements. Such a certificate not only acts as an assurance to the buyer of the stone's worth, but, if it contains sufficient detail, can be used as a method of identifying that particular stone should the need ever arise.

Means of irrefutably proving a diamond's identity is also very much in the interest of insurance companies, police, and jewellers themselves, who could become involved in disputes over gems left for re-setting or cleaning.

The Gemprint machine

There have been many claims made over the years for special methods of 'fingerprinting' diamonds so that they can be positively identified. However, the one commercial equipment that has reached the market and has been put into use is the Gemprint (*Figure 14.23*). This instrument was invented and developed at the Weizmann Institute of Science in Israel, and is exclusively manufactured by Kulso Ltd, of Haifa. The North American marketing rights for the Gemprint were subsequently granted to Mr. W. Levine of Chicago, who then founded Gemprint Ltd, to establish a central

Figure 14.23
The Gemprint 2000 produces a 'Fingerprint' picture of a diamond by using the gem to reflect and refract a laser beam onto a polaroid film (Gemprint Ltd)



registry containing a Gemprint identification for every gem recorded by Gemprint instruments.

In the Gemprint, the scientists and engineers at the Weizmann Institute have used a laser as a source of coherent light to produce a pattern of reflected and refracted light spots, which is unique to each gem. The instrument records on film the unique pattern of light spots caused by minute and individualistic differences in symmetry and polish on a stone's facets. There are a number of other factors which contribute to the pattern, such as individual variations in hardness.

The basic components of the Gemprint machine are:

1. A small low-power laser
2. Shutter
3. First lens
4. Polaroid film holder
5. Pinhole screen
6. Second lens
7. Adjustable gemstone holder.

Light generated by the laser passes through a polarising filter and the shutter, and is then focused by the first lens onto the pinhole screen. Laser light passes through the pinhole to the second lens which provides a parallel light beam. When the gemstone is placed in this beam, reflections and refractions from the facets return through the lens and appear on the front (gem) side of the pinhole screen.

The gem must be positioned in its holder so that the reflection from the gem's table is directed into the pinhole. There is only one position in which this reflection can be orientated with the pinhole. This enables subsequent prints of the same gem to be matched with the original. (If any facet of the diamond is re-polished, however, this will alter the pattern of the reflected light and make it impossible to match the diamond with the original print.) When the gemstone is correctly positioned, a recording of the spot pattern is made using positive/negative film on the pinhole screen. The film used is Polaroid Type 55 P/N.

In the latest version, Model 2000, a photocell senses the brightest reflection, and when this reflection is correctly orientated, an align light is energised. Without correct orientation it is not possible to take a photo. A computer is used to digitize the Gemprint photo for easy retrieval. Model 2000 is one third smaller than the original version, and measures 50 cm long. ($4800).

Nomarski interference contrast

A modified version of Nomarski interference contrast which was originally developed by R. V. Huddlestone at Diamond Grading Laboratories Ltd, is used to provide an 'Identiprint' photograph on the diamond grading certificates issued by the Independent Gemstone Testing Laboratory, Hatton Garden, London.

With this system of microscope illumination, the surface contrast of the diamond's facets can be enhanced to a point where both polishing lines and the surface manifestations of the underlying crystal structure can be made clearly visible. Photographic records of these unique features can then be used as a means of identifying individual diamonds. Because these features continue deep into the diamond, they are still visible under Nomarski interference contrast conditions, even if the diamond is re-polished.

X-ray topography

An alternative method for 'fingerprinting' diamonds, developed to a laboratory stage, uses X-ray topography, which picks out the unique lattice structure differences inside the gem rather than the surface features. The X-ray topography technique, which was investigated by De Beers Industrial Diamond Division in their laboratory at Charters, Ascot, is described in Chapter 15.

The Okuda process

Another technique which can be included under the heading of fingerprinting has been developed commercially by the Okuda Jewelry Technical Institute Co Ltd, of Tokyo. It is radically different from the methods so far described in that it identifies a polished diamond by printing an individual code on the table facet of the diamond. This code, which includes the diamond's colour grade, clarity grade, and carat weight, is printed into the surface of the diamond using a metal fusion process.

The printed code can only be made visible by means of a 20× microscope using coaxial illumination. It is applied to the surface of the diamond's table by means of photomask etching techniques as employed in the semiconductor industry. The table is first coated with a photosensitive emulsion, and the code characters from a microfilm are exposed onto this surface. Grains of a special metallic preparation ae deposited on the exposed area and are fused into the diamond's surface. Finally, the emulsion layer is dissolved away, leaving behind the fused metallic code letters. The printing process takes about two hours.

The printed code (see *Figure 14.24*) is only 1–1.5 mm thick, and the width of the printed characters is 10 micrometers. The method is called SPD (Scientifically Printed Diamond) and is backed by a comprehensive group which includes a grading committee, certifying organisations (authorised by the Japan SPD Association), qualified distributors and affiliated retailers.

As the metal fusion process is specific to diamond, it cannot be physically applied to simulants, so that its presence on a stone proves that

Figure 14.24
Metallic code letters, fused into the table facet of a diamond, as viewed under a 20× Okuda microscope (Okuda Jewelry Technical Institute Co Ltd)

it is a diamond. Each diamond bearing the printed code also has a serially numbered diamond card carrying the same identifying information. The Okuda diamond grading microscope (see Chapter 4) is fitted with the necessary contrast illumination to make the SPD code visible.

The GE process

This technique, developed by the American General Electric Company, enables secret invisible codes to be implanted beneath the surface of the diamond. It is based on an ion implantation process which affects the electrical conductivity of the diamond. To make the code visible, the diamond is given an electrostatic charge by rubbing its surface with a piece of silk or cotton. This charge collects in the region where the ion pattern has been implanted and can be made visible by dusting the diamond with a special powder which clings only to the charged region.

References

1. Read, P. G., 'Automation in the sorting of rough gem diamonds', *Journal of Gemmology* (October 1977).
   Read, P. G., 'Automatic weighing of rough gem diamonds', *Proceedings of 1977 Diamond Conference,* Reading University
2. Colour classification of rough gem diamonds of 2.0 carats upwards:
   - Extra Collection (top colour)
   - Collection
   - Extra Special
   - Blue
   - Fine
   - White
3. Colour classification of rough gem diamonds below 2.0 carats:
   - Collection
   - 1st Colour
   - 2nd Colour
4. Rough gem diamond shapes:
   - Stones } currently these two are combined;
   - Shapes } under 2.0 carats, they are called melée
   - Cleavages – Called Chips when under 2.0 carats
   - Macles
   - Flats
5. Rough gem diamond qualities:
   2.0 carats and over – Stones and shapes divided into 5 qualities; cleavages, macles and flats into 4 qualities.
   Under 2.0 carats – Melée (stones and shapes), 4 qualities (finest, fine, dark, black); chips, macles and flats, 2 qualities (fine and 'chips/macles/flats')
6. Confédération Internationale des Bijoutiers, Joaillers et Orfèvres.
7. Eickhorst, M., 'Inventor explains need for accurate instruments', *The Diamond News and South African Jeweller* (January 1977)

Table 14.4

Manufacturers or Suppliers (see Appendix A for addresses)	*Diamond equipment*					*Carat balances*	
	Sieves	*Counters*	*Lamps*	*Gauges (weight)*	*Proportion analysers*	*Mechanical*	*Electronic*
Nihon Hoseki-Kizai Co., Ltd			●	●			●
Eickhorst			●		●		
Gem Instruments Corp			●	●	●	●*	●
Gemmological Instruments Ltd				●		*	
Gemphot					●		
GAAJ			●		●		
GfD			●		●		
Haigis	●					●*	
Industrial Vibrators Ltd.	●						
Topcon					●		
Krüss			●				
Rubin	●	●	●	●	●	●*	●
Sauter						●	●
Mettler/Gallenkamp						●	●
Neill Tools Ltd.				●			
Sartorius						●	●
Hans-Günter Schneider					●		

* Also portable type.

15 Reserarch Laboratory Equipment

The electron-spin resonance spectrometer. X-ray topography. The electron microprobe. The 'Luminoscope'. The scanning electron microscope. Future applications of research techniques.

While much of the pure research that is done in scientific establishments (such as the De Beers Diamond Research Laboratory in Johannesburg) has little direct influence on gemmology, the experimental work done with the following equipment has been particularly relevant to our understanding of gemstones.

THE ELECTRON-SPIN RESONANCE SPECTROMETER

Following research into fundamental diamond characteristics at the Diamond Research Laboratory (DRL), Johannesburg, their Director of Research, Dr. J. F. H. Custers in the 1950's, proposed that the existing classification of diamonds into nitrogen-contaminated Type I and the purer nitrogen-free Type II should be further sub-divided into Type I, Type IIa and Type IIb, the latter to include nitrogen-free diamonds which contain boron in their structure. Because of the boron impurity in the Type IIb's, these diamonds possess semi-conductor properties and are thus capable of passing an electric current.

Subsequent work showed that both nitrogen and boron affect the body colour of diamond. Nitrogen absorbs light at the blue end of the spectrum, and causes the yellow tints which are seen in the Cape Series, and boron in the rare Type IIb diamonds produces the natural blue stones as recovered from the Premier mine at Cullinan near Pretoria, South Africa.

For a while there appeared to be a conflict of data, as it was known that some Type I diamonds existed which contained relatively large amounts of nitrogen, but which were of top colour, and not a deep yellow as experimental results implied. It was then found that there were two ways in which nitrogen atoms are grouped in the diamond lattice.

If the nitrogen content of the diamond is low, the nitrogen atoms are dispersed throughout the crystal lattice, and produce a yellowish body colour. However, if the nitrogen content is high, the majority of the nitrogen atoms are not dispersed throughout the lattice, but are grouped together in small clusters of atoms called 'platelets'. These have no affect on the diamond's colour as they only absorb light in the ultra-violet end of the spectrum. The colour of these diamonds is therefore due to the small amount of dispersed nitrogen and not the much larger amount of nitrogen in platelets.

From this evidence, it was possible to subdivide Type I diamonds into Type 1a, which contains nitrogen mainly in platelets, and Type Ib which is a much smaller group of diamonds containing nitrogen in dispersed form. The majority of diamonds are a mixture of Type Ib (giving the yellow tints of the Cape Series) and Type Ia.

The direct relationship between the amount of dispersed nitrogen in a diamond and the yellowness of that diamond was established at the DRL[1] by the use of an electron-spin resonance spectrometer, which provides a non-destructive means of measuring the amount of the dispersed nitrogen atoms in the diamond lattice.

The carbon atom (of which diamond is composed) has a 'valency' of four; that is, it has an electron orbital shell containing four electrons which enables it to link to four other carbon atoms to form a geometric crystal lattice.

In Type I diamonds, each dispersed nitrogen atom replaces a carbon atom in the diamond lattice, and as the nitrogen atom has a valency of five, this results in a free uncommitted electron associated with the nitrogen atom. This free electron behaves like a tiny bar magnet and, under the influence of the nitrogen nucleus, has distinguishing magnetic resonances in the 9.5 GHz microwave region of the electromagnetic spectrum. These resonances can be detected and quantified on the ESR spectrometer[2].

The Varian E109 spectrometer

The Varian E109 spectrometer shown in *Figure 15.1* is made by Palo Alto Associates, California, and consists of three basic parts:

1. A magnet assembly (maximum field strength, 10 kilogauss) with a specimen module positioned in a cavity between the pole pieces.
2. A microwave generator/bridge. This contains a tunable klystron valve which generates the microwave energy, and a microwave bridge to detect the absorption of that energy by the specimen. The output of the microwave generator is fed to the specimen cavity in the magnet assembly.
3. A control unit (*Figure 15.2*) which, among other things, enables the field of the magnetic assembly, and the scanning range over which the field is to be swept, to be adjusted. This unit also contains a chart recorder to plot the microwave absorption spectrum of the specimen and thus reveal (by the level of absorption) the amount of nitrogen present in the lattice of the specimen.

Spectrometer tests

The ESR spectrometer tests are made as follows. First the diamond under test is placed in the specimen module, and the klystron in the microwave bridge is tuned to the resonant frequency of the magnet cavity. The bridge is then adjusted for an exact balance.

For work on nitrogen defects in diamond, the resonance is adjusted to 9.5 GHz, the field strength of the magnet assembly is set to approximately

Figure 15.1
The Varian E109 E.S.R. spectrometer. The magnet assembly is on the right-hand side, with a waveguide tube leading up from the sample cavity between the magnet's pole pieces to the microwave generator above it. On the left is the control unit (P. G. Read/De Beers Industrial Diamonds Ltd.)

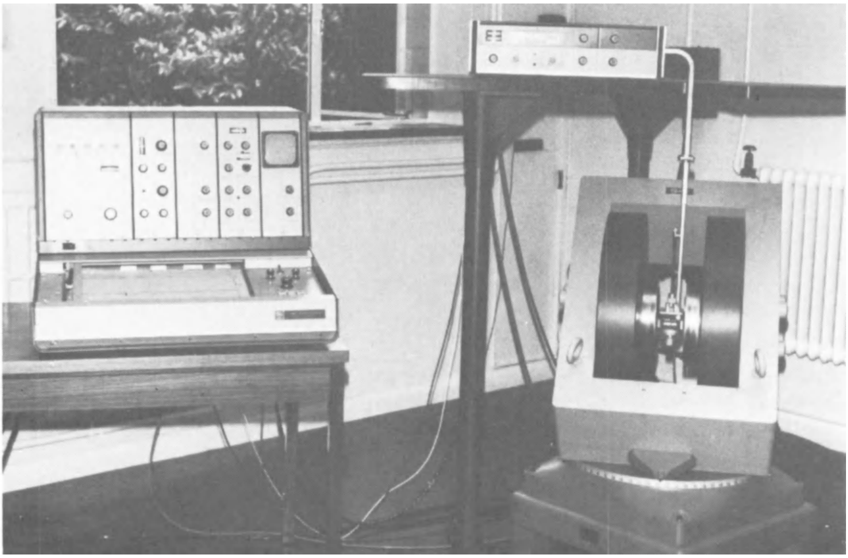
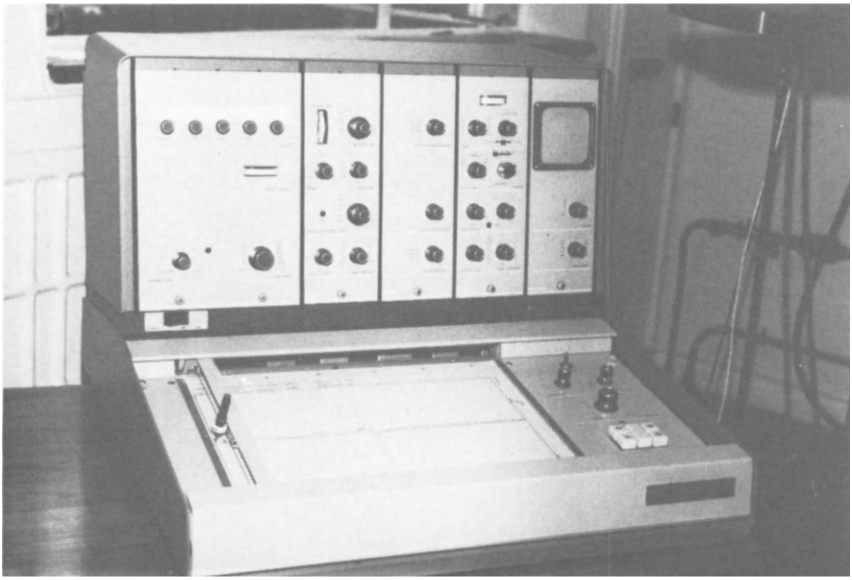


Figure 15.2
The ESR spectrometer control unit showing a diamond/nitrogen spectrum on the integral chart recorder (P. G. Read/De Beers Industrial Diamonds Ltd.)

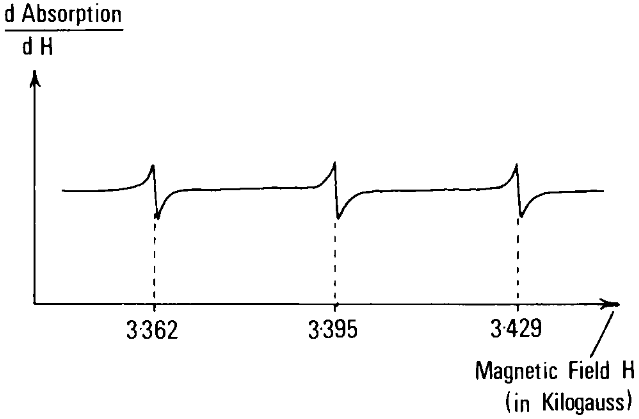


3.4 kilogauss, and the range over which the field is swept is set typically to ±50 gauss.

When the test is run, the magnetic resonances in the nitrogen defects result in microwave energy being absorbed at characteristic field strengths as the magnetic field is swept across its scanning range. This absorption unbalances the microwave bridge, the unbalance being recorded as the vertical component on a chart whose horizontal scale is related to the scanning range of the field. Thus the amount of absorption, and hence the quantity of nitrogen and degree of yellowness in the diamond, is indicated by the vertical deflections in the recorded trace.

For a more readable spectrum, the magnetic field is also modulated at 100 kHz, and by the use of a phase-sensitive detector, this results in broad differentiated responses in the recorded absorption spectrum. A typical ESR spectrum for diamond is shown in *Figure 15.3*. The single differentiated peak in the centre is due to the spin resonance of the nitrogen electron, while the two outer responses are due to the modifying effect of the nitrogen nucleus on this resonance. The spectrum was taken with the magnetic field parallel with the cubic (100) plane. Spectra taken with the field parallel with the dodecahedral (110) and octahedral (111) planes show twin outer responses.

Figure 15.3
A typical ESR spectrum for diamond (taken with the magnetic field parallel with the cube plane) showing the differentiated microwave absorption peak in the centre caused by the spin resonance of 'free' nitrogen electrons in the lattice



It is interesting to note that C. A. Schiffmann[3] of the Gübelin Laboratory, Lucerne, used a prototype ESR spectrometer in the laboratory of Beckman Instruments, Geneva, to distinguish between genuine sea-water pearls and cultured salt-water pearls with mother-of-pearl nuclei. The genuine pearls showed an almost flat ESR trace containing low amplitude high-frequency 'noise', while the cultured pearls showed traces containing peaks of a much higher amplitude and lower frequency. The irregular absorption peaks in the latter were thought to be due to a small content of manganese.

X-RAY TOPOGRAPHY

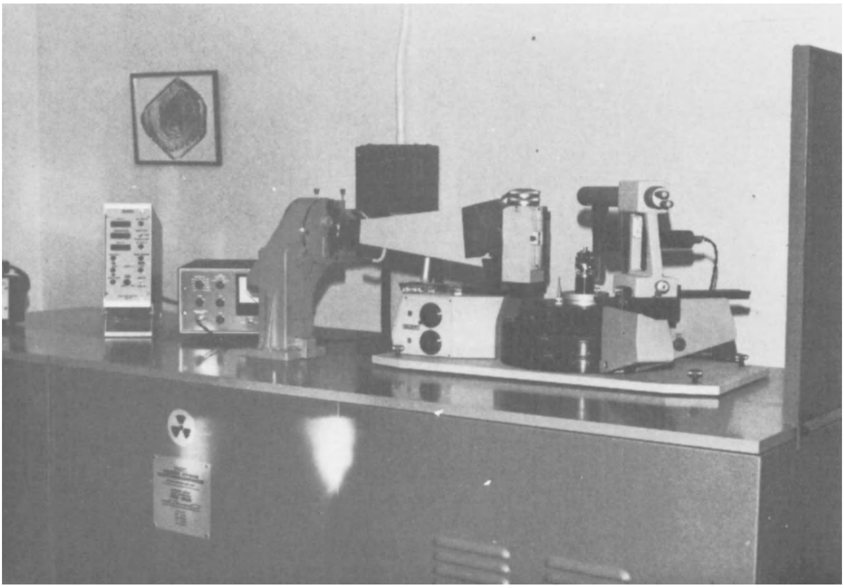
Work done by Dr. A. R. Lang and Dr. G. S.Woods[4] in the H.H. Wills Physics Laboratory at Bristol University has demonstrated that X-ray topographic 'maps' of internal defects in a diamond's lattice can unambiguously identify a polished stone with the rough stone from which it was cut.

This work has also shown that an X-ray topographic recording on film can serve to identify a polished gem even though it may have been recut. It is this aspect of X-ray 'fingerprinting' that is of particular interest in the identification of polished diamonds.

Unfortunately, the equipment used to produce an X-ray topographic photograph of a diamond is both bulky and expensive. In the present state of the technique's development, it is therefore more in the province of the research laboratory than the grading laboratory. Depending on the intensity of the X-ray source and the sensitivity of the photographic emulsion, the time taken to produce an X-ray topographic print may be hours rather than minutes. However, it is possible that further development of the equipment and the technique may reduce both the bulk and the time factors to a more practical gem laboratory level.

A suitable equipment for X-ray topography work is shown in *Figure 15.4*. The bulk of the equipment comprises a GX20 Rotating Anode X-Ray Generator, manufactured by the Neutron Divison of Elliott Bros (London)

Figure 15.4
An X-ray topography equipment comprising an X-ray generator (below) and a Bristol–Lang topograph camera (above) (P. G. Read/De Beers Industrial Diamonds Ltd.)



Ltd, at Borehamwood. On this unit is mounted a Bristol-Lang Topography Camera.

Figure 15.5 shows the Bristol-Lang camera in more detail. The camera consists of a spectrometer type table on which the angular positions of the specimen and the film holder can be adjusted relative to the source. The source in this case is a vertical ribbon-like beam of collimated X-rays (10 to 100 microns wide) which emerge from the slit on the left-hand side of the diamond specimen in *Figure 15.5*.

The two most important X-ray topographic techniques for use in the fingerprinting of diamonds result in the production of a 'section' topograph and a 'projection' topograph. In the section topograph, the thin ribbon of X-rays is used to penetrate a slice of the diamond. The diamond is orientated so that the X-rays are diffracted by the atomic layers in the crystal lattice, and emerge at an angle to the incident beam. The emerging X-rays fall on a photographic plate placed close to the diamond, but shielded from the direct beam. Any defects in the crystal lattice will deflect

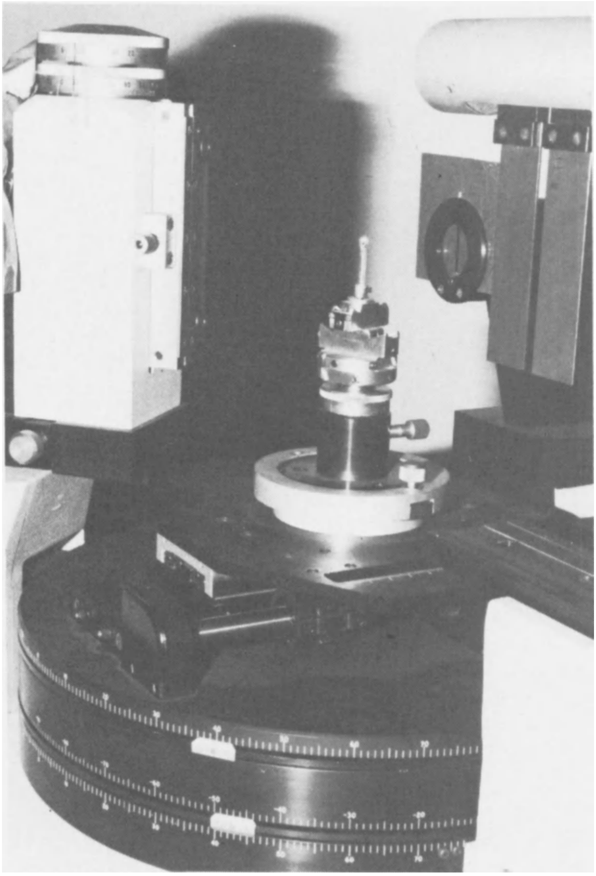


Figure 15.5
A collimated vertical 'ribbon' of X-rays emerges from a slit in the block to the left of the sample holder, and is diffracted by the atomic layers in the diamond under test. The emerging X-rays are used to expose a photographic plate placed behind the slotted shield immediately to the right of the diamond (P. G. Read/De Beers Industrial Diamonds Ltd.)

the beam more strongly and be recorded as darker areas on the photographic plate. A photographic record is therefore produced which reveals a pattern of crystal defects in the slice of the crystal penetrated by the X-rays.

In the projection topograph, the diamond and the frame holding the photographic film or plate are together moved backwards and forwards through the X-ray beam. In effect, the ribbon-like beam scans the whole of the diamond, and the image formed on the photographic plate is a parallel-beam projection of the internal lattice defects of the complete diamond.

Two typical X-ray topography photographs are shown in *Figure 15.6* and *15.7*. The upper photograph shows a series of lattice defects in a 1 carat rough diamond crystal of octahedral shape, and having no visible flaws. A large defect is seen in the upper half of the stone, with several needle-like defects crossing the large one and pointing towards the centre. In the centre of the stone is a nail-shaped defect.

The lower photograph (*Figure 15.7*) shows a polished brilliant cut diamond produced from the rough stone in *Figure 15.6*. The brilliant has been cut from the upper part of the octahedron, and the large defect, the lines and the nail-shaped image are still clearly visible. From the photographs it is fairly obvious that no amount of re-polishing of the stone will remove these defects as they are within the body of the stone (this is shown by taking similar X-ray topographs in different directions).

It is fortunate that the refractive index of diamond is virtually unity at the X-ray wavelengths used for fingerprinting, as this removes any problems that might have been caused by irregular shape or surface roughness in the diamond specimen. Refraction of the X-ray beam may, however, take place if the technique is applied to other gemstones whose R.I. is considerably lower than that of diamond, and unless X-rays of an appropriate wavelength can be used this may restrict the technique to the fingerprinting of diamonds. Despite this drawback, X-ray topography has been used to distinguish natural from synthetic emerald[5].

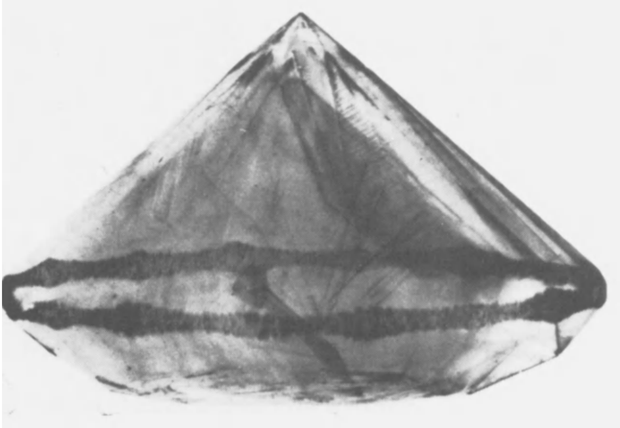
The absorption by diamond of the more penetrating radiations used in X-ray topography is so low that even very large diamonds can be completely irradiated without the X-ray beam suffering excessive attenuation. Nor is there any damage done to the diamond by the radiation. Some diamonds have in fact been X-rayed so often that their accumulated X-ray dose would be equivalent to several hundred fingerprinting operations, and no detectable colour change has been produced.

THE ELECTRON MICROPROBE

This is perhaps one of the more recent 'tools' to be added to the range of diagnostic equipments available to the research gemmologist. Its prime value is that it permits the rapid non-destructive analysis of gemstone inclusions down to a fraction of a millimetre in width, provided that these are exposed at the surface of the gem.

Figure 15.6
A projection topograph taken showing the lattice defects in a one carat rough diamond (Industrial Diamond Review)

Figure 15.7
A projection topograph taken of a round brilliant-cut diamond produced from the rough stone shown in Figure 15.6. The lattice defects in the rough crystal can still be seen clearly in the polished diamond (Industrial Diavond Review)



The following description of the microprobe is based on an article[6] by Mr. P. J. Dunn of the Department of Mineral Sciences, Smithsonian Institution, Washington.

The ARL-SEMQ Microprobe consists of four basic components:

1. The electron gun
2. The spectrometer
3. An electronic recording system
4. A microscope.

The electron gun is fitted in the cylindrical vacuum chamber section of the instrument, and contains a tungsten filament. A negative 15–20 kV potential is applied to the filament relative to the vacuum chamber, and the filament then acts as a directly-heated cathode and emits electrons. The electrons pass through a control aperture and are then focused by electromagnetic 'lenses' onto the specimen to be analysed. With modern microprobes, this beam can be focused to a diameter of 0.001 mm.

The gem to be analysed is positioned under the focused beam of electrons, using the microscope to observe the sample. As the electrons hit the surface of the gem, X-radiation is emitted, each element bombarded by the electrons emitting its characteristic radiation. This X-radiation is detected and its wavelength measured by special spectrometers which record the information and transmit it in the form of digital pulses to a teletype, a cardpunch or a computer terminal for further processing.

Tables of emission spectra are then consulted to find the elements responsible for producing the recorded X-radiation wavelengths. For a quantitative analysis, the gem specimen is compared with standards, which are natural minerals or synthetic compounds whose composition is well known. The selection of the appropriate standard for an analysis is a critical one. For the best accuracy, the proportion of the element to be analysed should be similar in both the standard and the specimen. It also helps if the atomic structures are similar.

If a peridot is to be analysed, for example, standards are chosen for iron, magnesium and silicon, the primary constituents of peridot. Since peridot has a low iron and a high magnesium content, an analysed mineral of the peridot variety is chosen with comparable constituents to act as a composite standard. The spectrometers are then set to record the wavelengths for iron, magnesium and silicon. The X-ray intensities for each of the standard elements in the known sample are next determined, and the intensities of the X-rays emitted from the unknown sample are also recorded under identical conditions.

These measurements may take from 10 to 100 seconds on each point on a sample, and from 10 to 15 points may be used on each sample to ensure an accurate analysis. A final check is made by again measuring the X-ray intensities of the elements in the known sample. The spectrometers are then de-tuned from the wavelengths of the elements being analysed so that the background radiation caused by scattered X-rays can be measured.

Finally, the background radiation measurements are subtracted from the intensity of both the known and unknown peridot samples, and the amounts of the constituent elements in the unknown sample are calculated by using the ratios of the two sets of intensity readings.

For a precise analysis, it is necessary to make a number of corrections to the rough data. Backscatter, fluorescence and absorption, due to the presence of other elements in the sample, have to be allowed for. As these corrections are complicated and are most laborious when done by hand, the work is usually done by a computer. Microprobes can also be connected on-line to a computer to provide final analyses within minutes. Computer data reduction programs are quite varied, and large flexible ones such as those in operation at the Smithsonian Institution can handle a large number of samples, perform all necessary calculations and corrections, and also provide a number of options which allow the research gemmologist to select the preferred format for his analysis.

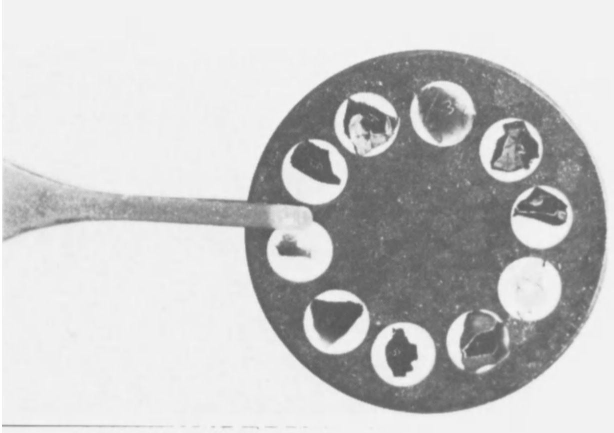


Figure 15.8
A sample disc containing ten fragments of tourmaline ready for insertion in the microprobe chamber (Smithsonian Institution)

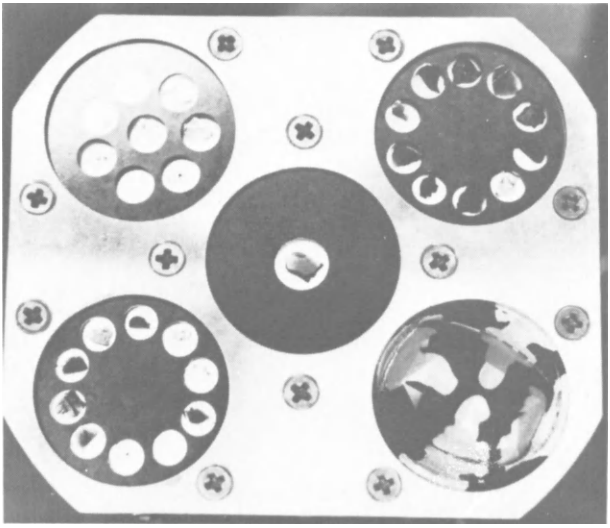


Figure 15.9
A module containing several sample discs ready for loading into the vacuum chamber (Smithsonian Institution)

The ARL-SEMQ electron microprobe unit just described is installed in the Department of Mineral Sciences at the Smithsonian Institution, Washington. It is capable of analysing nine elements simultaneously. Six of the nine spectrometers are set permanently to analyse for silicon, alumium, iron, magnesium, calcium and potassium. The remaining three can be used for scanning, and can be set for any three additional elements the analyst wishes to examine.

Figure 15.8 shows a sample disc containing ten fragments of tourmaline ready for analysis. *Figure 15.9* shows several sample discs loaded in a module which is ready for insertion in the microprobe.

When the gem tests do not have to be non-destructive, the samples are first cemented in place in the disc with epoxy. After curing, the disc is ground down to expose the gem grains. They are then highly polished to a mirror-like finish with diamond abrasives.

In the case of inclusion studies, the task is much more time-consuming. Each piece of rough is mounted in a separate disc so that the inclusion can be seen. The gem sample is then laboriously ground down to expose the selected inclusion. This work takes much skill and patience.

Where non-destructive analysis of a faceted gem is required, different procedures are followed. The gem is mounted in an individual sample holder by means of an Apiezon high-vacuum clay. Before the clay sets, the surface of the gem to be analysed is made horizontal and flush with the top edge of the holder by means of a levelling press.

As the gem sample is almost certain to be non-conducting, it then has to be coated with carbon so that the electrons hitting its surface can be leaked away (otherwise the gem would become charged and would repel the electron beam). Because the carbon coating is very thin, there may be breaks in the conducting surface at the juncture with the sample holder. To bridge these gaps, samples are usually coated with silver or gold paint (see bottom right-hand specimen in *Figure 15.9*).

In spite of its many advantages, the microprobe does have some limiting factors. For instance, it cannot detect with reliability the presence of elements with an atomic number below 9. Hence it is not possible to analyse for beryllium, boron, lithium and oxygen. The extremely high cost of a microprobe is another severe limitation. A modern machine, with on-line computation and peripherals can cost in the region of $250 000.

THE LUMINOSCOPE

This is a reasonably compact and economical instrument (at least in terms of research laboratory equipment) designed to enable small specimens to be observed under electron bombardment. The particular application to which the instrument is best suited is the observation of cathodoluminescence[7].

Cathodoluminescence is the visible fluorescence produced when a beam of electrons strikes the surface of a specimen. This fluorescent display can yield much information about a specimen since both the colour and intensity are dependent on very small changes in the concentration of trace impurities, as well as on the matrix substance and the way in which the impurities are incorporated in the base material.

Cathodoluminescence is used in studies concerning the concentration of rare earths[8, 9] (down to six parts in one thousand million), the degree of perfection of synthetic crystals, and the identification of minerals in conglomerates.

The Luminoscope is manufactured by the Nuclide Corporation, AGV Division, USA. It consists of a specimen vacuum chamber and a control unit (*Figure 15.10*). The specimen chamber (*Figure 15.11*) is flat enough to permit it to be placed on a microscope stage, but is still capable of taking a specimen up to 2 × 3 × 0.5 inches in overall dimensions. A ⅛ in. thick lead glass window in the top and bottom of the chamber permits incident or transmitted illumination of the specimen under observation. A stage is provided for the specimen within the chamber and this can be indexed in the X and Y directions by means of two external controls.

The electron beam is generated by a cold cathode 'gun' mounted at the right hand end of the chamber, the relatively soft vacuum in the chamber (15–25 millitorr) preventing static charges from developing on the specimen.

The control unit contains the EHT supply for the gun cathode, which is variable from 0 to 18kV. A safety current limit preset control can be adjusted from 8 microamps to 2 milliamps to set the current level at which the EHT voltage is switched off. A push button is provided which switches off the EHT and turns on the microscope light to enable rapid alternate observation of the specimen under visible light or electron bombardment. Provision is also made for the control of a vacuum pump, which can be quite a small one as the pumping capacity and vacuum requirements are modest. Chamber vacuum pressure is displayed on a meter which is fed from a transducer on the chamber.

The gun is fitted with collimating anodes, and an electrostatic lens electrode gives control of the electron beam focus via a knob on the control unit.

The electron beam is guided and deflected downwards onto the specimen by means of a permanent-magnet deflection assembly which can be moved laterally across the top of the chamber.

When in use, the electron beam can either be defocused so as to irradiate a group of specimens, or it can be focused to a spot of approximately 4 mm^2 to energise a single stone.

The Luminoscope shown in *Figure 15.10* is the one in use in the Crystallography Department at University College, London. It is used there to investigate the cathodoluminescent properties of diamonds[10], and to act as a selector for diamonds having special features which are then investigated in detail on a scanning electron microscope.

The Leitz contrasting device, which is used to increase the contrast of specimens by vacuum deposition of selected particles, can also be used for cathode luminescent work by changing the lid of the vacuum chamber and increasing the EHT to 15 kV.

Figure 15.10
A view of the Luminoscope as used in the crystallography laboratory of University College, London, for the study of cathodoluminescence in diamonds. The specimen chamber is in position on the microscope stage. The associated control unit is on the right (P. G. Read/University College)

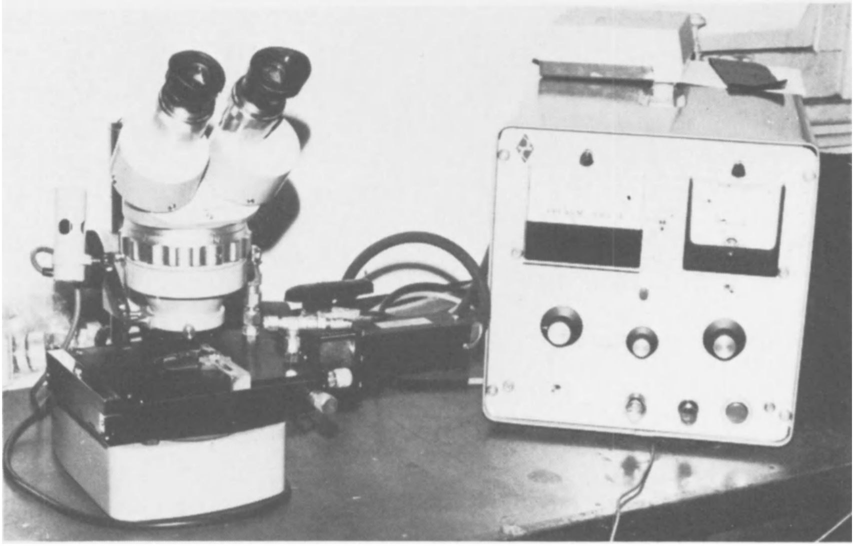
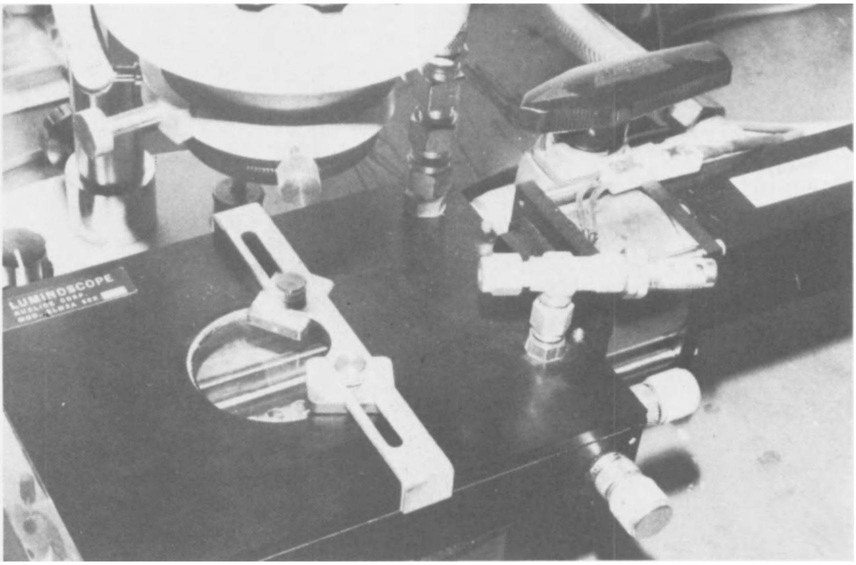


Figure 15.11
The specimen chamber has two parallel windows to enable the specimen to be illuminated by the microscope's sub-stage light source. The cold-cathode gun assembly is on the right of the chamber (P. G. Read/University College)



THE SCANNING ELECTRON MICROSCOPE

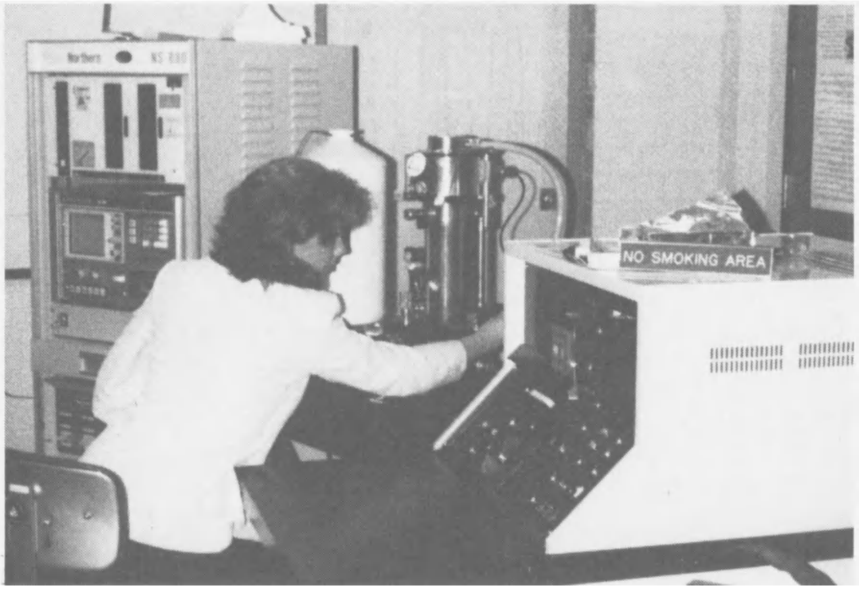
For gemmological purposes, one of the most important applications of the scanning electron microscope (SEM) is its use as an energy dispersive spectrometer[11]. In its primary function as a microscope, the SEM uses a focused beam of electrons to bombard the sample under test and thereby cause the emission of secondary electrons from the sample's surface. The varying intensity and distribution pattern of these secondary electrons are detected and used to produce a picture of the sample's surface on a video display screen.

The advantage of a SEM over an optical microscope is that electrons have a much shorter wavelength than visible light, and can therefore reveal much smaller surface features. Magnifications of up to 200 000× are possible with a SEM.

In a similar configuration to the electron microprobe, the SEM uses an electron gun consisting of a directly-heated tungsten filament in a vacuum chamber. The electron beam is produced by applying a high negative potential to the filament (typically 20 to 25 kV), and focusing the emitted electrons onto the sample in the vacuum chamber. Scanning and magnification is controlled by the electronic manipulation of the magnetic lens fields.

In its energy dispersive spectrometer rôle, the SEM (*Figure 15.12*) is used to evaluate the X-rays produced when the electron beam strikes the

Figure 15.12
An electron scanning microscope used as an energy dispersive spectrometer to analyse the chemical composition of gemstones in the GIA research department, Santa Monica



gemstone under test. The X-rays, whose wavelengths are characteristic of the elements present in the specimen, are sampled by a special spectrometer detector, and displayed in graphic form on the video monitor. The display consists of an X-ray emission spectrum of the specimen, and provides an indication of the elements present. For a quantitative analysis of the chemical composition of the sample, the X-ray data is analysed by a computer, comparative calibration specimens being used in the same manner as described for the electron microprobe.

Future applications of research techniques

Optical scanning microscopes, which illuminate the specimen from the fine spot of light produced by scanning a cathode ray tube, do not produce a more detailed picture than the standard optical microscope, but because the technique lends itself to image processing methods, it can be used to enhance the contrast of the resulting video image. The main disadvantage of the optical scanning method is that the scanning spot developed by the cathode ray tube is limited in brightness. This problem has now been overcome by the use of a laser as the source of light. With this method, the specimen is scanned by the laser by moving the specimen mechanically in the laser beam[12].

Another technique, which may find an application in gemstone research, is photo-acoustic spectroscopy[13]. This measures the acoustic opacity of the sample as it is illuminated with a mechanically 'chopped' monochromatic light across the range of the visible spectrum. Its main advantage over transmission or reflectance spectroscopy is that only the light energy absorbed by the sample affects its acoustic absorption, and the technique is therefore not troubled by scattered or reflected radiation from the polished surface of the sample.

Raman spectroscopy[14] is a research technique which enables diagnostic absorption spectra in the infra-red to be detected in the visible region of the spectrum by means of a spectrophotometer. When a high-intensity light (such as a laser beam) falls on a surface, a minute amount of it undergoes Raman scattering. This scattered light is shorter in wavelength than the incident beam, the effect being caused by the excitation of molecular vibrations in the surface of the material. The degree of wavelength difference, or Raman shift, between the incident beam and the scattered light depends on the nature of the surface atoms and their structural bonding.

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16 Miscellaneous Items

Gem test equipment. Portable gem laboratories. Video microscopy. Jewellery photography. Anti-static products and devices. Anti-vibration pads and mounts. Optical filters. Materials. Catalogues.

This Chapter contains a miscellany of products and information which could not be classified under the headings of the preceding chapters. Some of the items have no direct connections with gemmology but have been included because of their usefulness in experimental work.

COMPARATIVE VALUE GUIDE

The figure quoted in US dollars after each item is intended only as a comparative value guide between similar items of equipment, and is based on an approximate 1982 price, less tax and carriage.

The Gem Diamond Pen (Gem Instrument Corporation/Gemmological Instruments Ltd./GfD) (*Figure 16.1*)

This instrument is designed to discriminate between diamond and those simulants having an R.I. above 1.8, and depends for its effectiveness on diamond's uniquely low water contact angle[1]. The body of the instrument is basically a draughting-type pen with an ink reservoir and a dispensing head. The ink reservoir is filled with a special non-drying viscous fluid containing inert chemicals and a blue dye to make it easily visible.

The test kit consists of the pen, a pair of stainless steel locking tweezers, a quantity of polishing powder, a felt cleaning pad and a bottle containing the test liquid. Detailed instructions for the use of the pen are also included. ($27).

An important part of the test routine is the thorough cleaning of the gemstone's surface using the felt pad and the polishing powder. This precaution is necessary to ensure correct operation of the pen and to remove any possible surface coatings which would modify the stone's water contact angle.

When the stone has been thoroughly cleaned, it is held table facet uppermost and the tip of the pen pressed down vertically onto the facet and drawn slowly across its surface. If the stone is a diamond, the pen will draw a continuous line of 'ink' across the facet (*Figure 16.2*). If, however, the stone is a simulant (having an R.I. above 1.8), the liquid will not flow in a continuous line, but will break up into a series of droplets (*Figure 16.3*). (*Warning,* on simulants having an R.I. below 1.8, the pen will also draw a continuous line.)

Figure 16.1
The Gem Diamond Pen test kit (Gem Instruments Corporation)

Figure 16.2
A continuous line drawn with the Diamond Pen on the table facet of a diamond

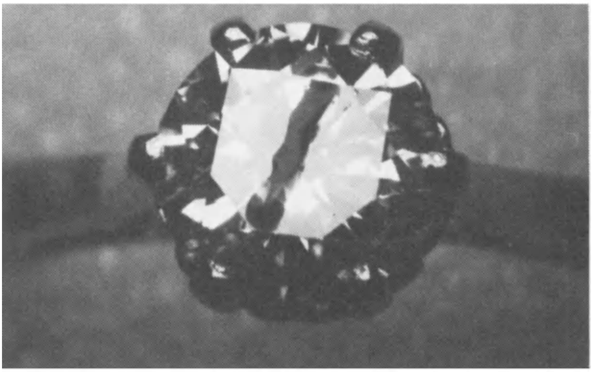
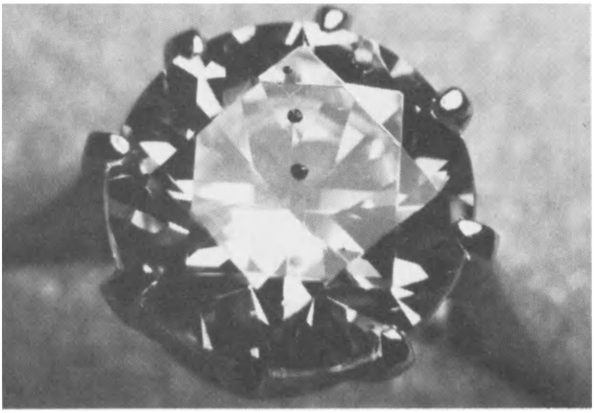


Figure 16.3
On a cubic zirconia, the line breaks up into droplets



When using the pen it is important first to check that the 'ink' is able to flow freely from the tip. This is done by gently shaking the pen and testing the flow on a piece of paper. Some practice is advisable on a known diamond as several attempts may be necessary before the 'ink' line can be started. A practical limiting factor to the test is the size of the stone.

The Color Stone Checker (Culti/Geshiro) (*Figure 16.4*)

This is a combination instrument comprising a reflectivity meter, a U-V fluorescence test unit and a U-V transparency indicator. It is designed to enable the less experienced gemmologist or jeweller to distinguish between natural alexandrites, emeralds, rubies and sapphires, and their many simulants and synthetics. ($700).

The reflectivity meter provides a means of rapidly screening out any simulants, the meter scale being directly calibrated to indicate the reflectivity readings obtained with natural/synthetic stones. Although the majority of simulants can be detected by this test, the reflectivity range of red garnets overlaps the readings for ruby, and with stones of this colour, use is made of the LW and SW U-V fluorescent test, the presence of a pink or red fluorescence in a stone indicating that it is probably a natural or a synthetic ruby, while a complete absence of fluorescence suggests that the stone may be a garnet.

For rubies which pass the reflectivity and U-V fluorescence tests (and for alexandrites, emeralds and sapphires which pass the reflectivity test), the final step is to establish whether the stone is natural or synthetic by means of the U-V transparency indicator.

Figure 16.4
The Color Stone Checker contains a reflectivity meter, a LW/SW U-V unit and a U-V transparency tester (Culti)

The amount of SW U-V transmitted by a natural gemstone is generally very low because of the presence of iron oxide impurities. In the majority of synthetic stones, however, there is very little iron oxide, and this results in a much higher SW U-V transparency.

The relative U-V transparency of natural and synthetic stones is measured in the Color Stone Checker by placing the gemstone over a test aperture in the instrument's U-V compartment. A photodiode beneath the aperture monitors the amount of U-V passing through the gemstone by means of a piece of fluorescing scheelite (which acts as a U-V/visible light converter). The amplified output of the photodiode is displayed as a reading on the reflectivity meter scale. Although the size of the stone influences the reading, the difference between the U-V transparency of natural and synthetic stones is large enough to swamp this effect.

For calibration purposes, a preset control enables the meter reading to be adjusted to 100% transparency in the absence of a gemstone. Because the actual amount of U-V transmitted is small, and varies from around 1% for a natural stone to 20% for a synthetic, test switch positions for the four principal coloured stones allow these readings to be expanded to correspond with green, yellow and red zones on the meter scale which indicate natural stones, an intermediate zone and synthetic stones.

The majority of natural and synthetic alexandrites, emeralds, rubies and sapphires can be separated by means of the U-V transparency test. Exceptions are some Sri Lankan sapphires and Burma rubies which contain very little iron oxide, and Kashan rubies which contain varying amounts of iron oxide.

The top of the tester consists of a hinged compartment containing the LW and SW U-V lamps, and this is fitted with a viewing hood which provides a convenient means of checking LW and SW U-V fluorescence in other gemstones.

PORTABLE GEM LABORATORIES

The need to make gem identifications away from the facilities of a well-equipped gem test laboratory has prompted several companies to market sets of gem test equipment packaged in a suitcase-type container.

One of these is the Krüss KA-4KRS (*Figure 16.5*) containing the KA-4 monocular zoom (10–25×) microscope (with 10×, 20× and dichroscope eyepieces), ER601 refractometer, portable spectroscope (with self-contained light source), tweezers, battery charger and tripod for the microscope, and immersion liquids. ($1725). Dimensions, 430 × 130 × 80 mm; weight 4.4 kg.

The Gem Mini-lab (*Figure 16.6*), available from the Gem Instrument Corporation, includes a refractometer, polariscope, prism spectroscope, dichroscope, emerald filter, tweezers, pen light, battery-powered light cube (acting as light source for the various instruments), battery charger and a Leveridge gauge. ($707). Dimensions, 300 × 260 × 130 mm; weight 3.5 kg.

The Gem Maxi-Lab (*Figure 16.7*), also available from the Gem Instruments Corporation, is fitted with a Custom 'A' Mk V Gemmolite stereo zoom microscope (10–63× using 15× eyepieces) complete with light-field and dark-field illumination (using a quartz halogen lamp). It includes a refractometer, prism wavelength spectroscope, polariscope filters (with konoscope lens) for attachment to the microscope light source, Leveridge gauge, thermal reaction tester, dichroscope, immersion cells and liquids, lenses, filters, a diamond colour grading light source and a carat weight scale.

A fibre optic light guide is also supplied and acts as an overhead source of illumination for the microscope, and as a light source for the refractometer. The rechargeable power unit operates from 110 V or 220 V, 50/60 Hz mains supplies, or from a 12 V car cigarette-lighter socket, and runs for two hours between charges. ($3495).

The Portlab (*Figure 16.8*) is manufactured by the Gemological Products Corporation of AIGS. It differs from the other versions in that it contains a LW/SW U-V unit. Other items included are a full-size stereo zoom microscope (10–63×), a built-in light-field/dark-field light-source (with fibre-optic probe), which can be powered from a 115–230 V supply or a re-chargeable battery pack, a refractometer, spectroscope, dichroscope, tweezers and a heavy liquid set. The U-V unit includes an interference-filter light source for the refractometer. ($3300).

Figure 16.5
The KA-4KRS portable gem test laboratory (Krüss)

Figure 16.6
The Gem Min-Lab (Gem Instruments Corporation)

Figure 16.7
The Gem Maxi-Lab contains a full-size microscope as well as grading and identification instruments (Gem Instruments Corporation)

Figure 16.8
The Portalab (AIGS Gemological Products Corporation)

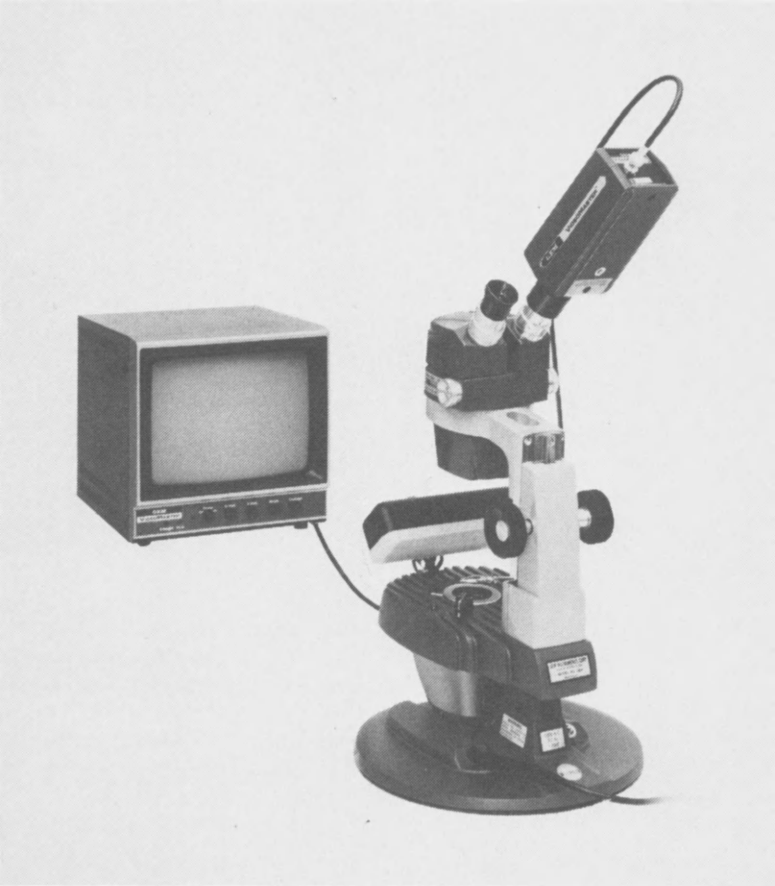
The Travelab is manufactured by the Antwerp Diamond Laboratory and is available from Rubin and Son. This unit is mainly intended for diamond grading and includes a Zeiss microscope, Eickhorst Colorscope (grading lamp), Topcon diamond proportion handscope, U-V lamp, grading tray, scales, tweezers, hand loupe and a set of cubic zirconia master stones. ($2267).

VIDEO MICROSCOPY

For teaching and general demonstration purposes it is possible to attach a video camera to a standard or a trinocular microscope, and display the resulting image on a video monitor.

The Gem VideoMaster (*Figure 16.9*), available from the Gem Instrument Corporation, consists of a black and white video camera (using a vidicon tube) with an eyepiece adaptor sleeve (suitable for use with all late version Gemolites and Diamond Grader microscopes) and a 9-in. video monitor. ($650). A proportion grading graticule is also available for the monitor screen.

Figure 16.9
The Gem VideoMaster can be fitted to Gemolite and Diamond Grader microscopes (Gem Instruments Corporation)



The Eickhorst range of microscopes can also be provided with a high-definition black and white video camera (using a newvicon tube) and 14-in. studio monitor (*Figure 16.10*). ($2163). The newvicon tube used in the camera has much greater sensitivity than the vidicon (particularly when used with tungsten lighting) and is proof against burn spots and blooming in the presence of highlights.

With the increasing availability of colour video cameras it should be mentioned that the professional 3-tube models are expensive (around $4000), while the much cheaper single-tube home video versions require a high level of light and are therefore not suitable for microscope work.

A black and white video camera is available for use with any of the Krüss stereo microscopes. The equipment (*Figure 16.11*) includes a modulator, power supply and a 12-in. monitor. ($900).

Figure 16.10
A video camera and monitor attached to a trinocular microscope in the Eickhorst range (Eickhorst)

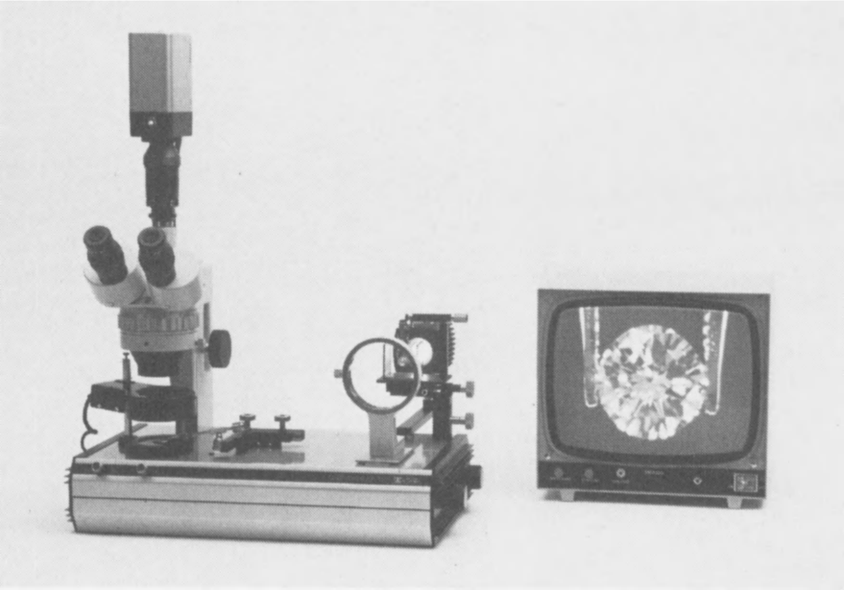
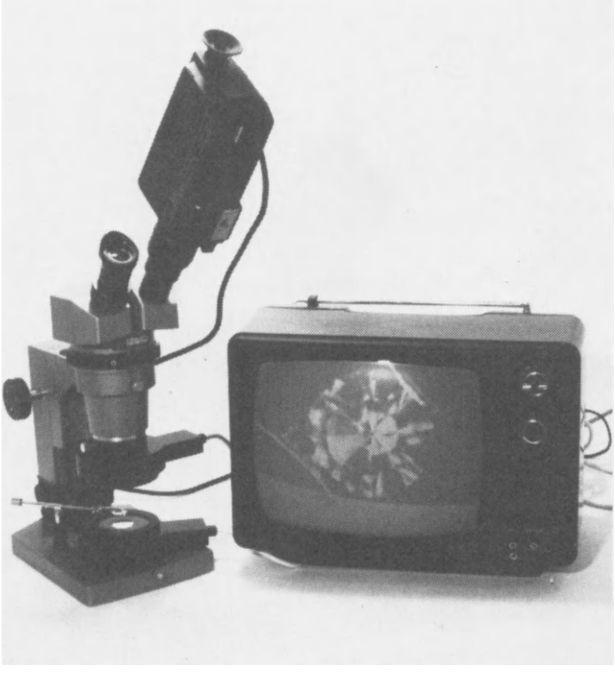


Figure 16.11
The Video-Installation can be fitted to any of the Krüss stereo microscopes (Krüss)



JEWELLERY PHOTOGRAPHY

Good quality colour photographs of jewellery are a useful means of recording individual designs, of compiling sample albums, and of providing identification details for insurance purposes.

The Gemphot equipment (*Figure 16.12*) enables jewellery to be photographed quickly and without specialised knowledge. Top quality prints or slides with a good depth of focus are ensured by the provision of a firm mounting for the camera, a high-level of built-in illumination and the choice of two pre-focused platform positions.

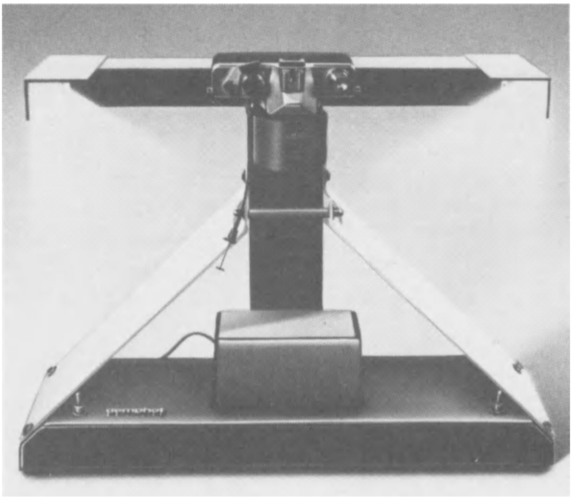


Figure 16.12
A camera stand and lighting platform for the photography of jewellery (GemPhot)

Shadowless illumination is obtained from two 300 W quartz-halogen lamps, whose light is evenly diffused by two white plastic filters. Model S is fitted with a Polaroid camera ($530), and Model XL is fitted with a 35 mm reflex camera ($750, without camera $448). These units are also available from Krüss.

It is also possible to photocopy suitable items of jewellery for appraisal reports and insurance purposes. R. C. Trigg of Cape Town has developed the technique and uses a Rank Xerox 230 to produce clear dimensional photocopies of rings, necklaces, etc.

ANTI-STATIC PRODUCTS AND DEVICES

The presence of static on electrically non-conducting surfaces can result in painful electric shocks being experienced by users of equipment. It can also cause the equipment to malfunction or give misleading readings. In some parts of the world where the air is very dry, and in air-conditioned offices where the relative humidity of the air is allowed to drop below 45%, static can also be produced by personnel walking across a highly insulating floor covering, such as a carpet fabricated from man-made fibres.

In this case it is the personnel who become statically charged rather than the equipment, and the static discharge shocks which are received are the result of touching the earthed equipment. In these circumstances the amount of energy in the static discharge is increased if the person is carrying a metal object, such as a weighpan, as this acts as an electrical capacitor.

In the semiconductor assembly industry, earthed chairs are provided and electrically conductive clothing is worn to prevent the production of static voltages that would otherwise destroy the electrically delicate solid-state devices. In hospital operating theatres, where a static discharge spark could ignite anaesthetic gases, special precautions have to be taken to prevent the production of static.

There are a variety of methods and devices to reduce or eliminate the production of static electricity. Perhaps the most basic of these is the control of the humidity of the surrounding air. It may be recalled from schooldays that if the static electricity experiments and demonstrations in the physics laboratory failed to work, this was invariably blamed on damp weather conditions!

In fact, in an atmosphere containing sufficient water vapour (above a relative humidity level of, say, 40–45%) static is much less likely to be developed. There is, of course, a practical limit to the level of humidity that can be tolerated, and above the 60% level, the atmosphere becomes unpleasantly humid to work in and there is danger of condensation, with resultant corrosion, on cold surfaces.

An alternative method of preventing the generation of static at source is to ionise (or electrically charge) the air in a room. This ionised air, in flowing over the statically charged surface, effectively discharges the static electricity. A variety of air ionisers are available from 3M United Kingdom Ltd, and these contain a radioactive isotope which ionises the surrounding air by means of 'soft' nuclear radiations. The ionisers are produced either in bar form, as ilustrated by the Type 210 Static Eliminator Bar in *Figure 16.13*, or as composite units comprising a static eliminator and an air blower. The bar type eliminator is intended for use either in close proximity to the surface to be discharged or for mounting in the outlet of an air-conditioning unit. The 3M static eliminators are available on a rental

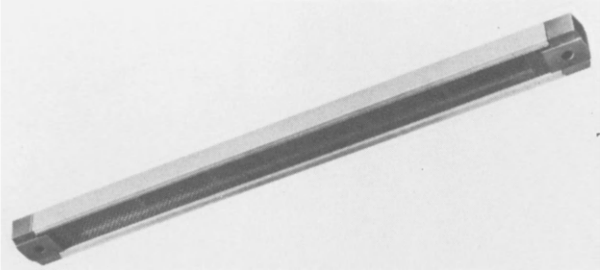


Figure 16.13
A bar type ionizer for the reduction of static (3M United Kingdom Ltd)

basis, and as the radioactive isotope has a relatively short half-life, the units are exchanged once a year.

For the elimination of static on smaller areas (i.e. the plastic windshield surrounding a balance pan; or plastic bags) a hand-operated ioniser manufactured by Zerostat Ltd is most effective. This device (*Figure 16.14*) consists of a piezo-elecric ceramic crystal (similar to the type used to provide a high-voltage spark in gas igniters) and a point-discharge electrode.

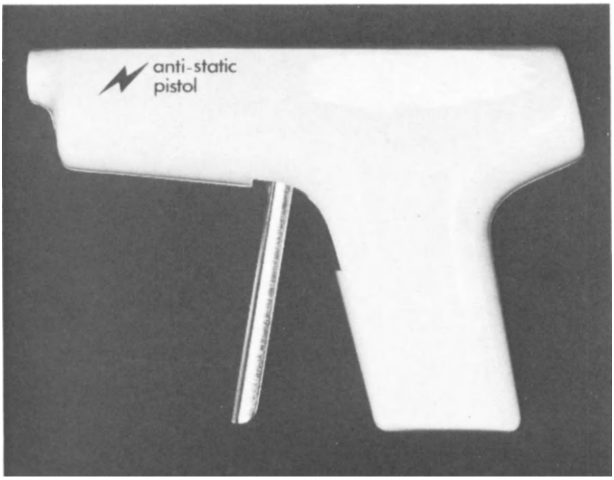


Figure 16.14
A hand-operated static eliminator (Zerostat)

When the trigger on the anti-static pistol is squeezed, the crystal is placed under stress and develops a high voltage which is applied to the discharge electrode. The voltage on the electrode ionises the surrounding air positively, and these positively charged ions are attracted to any local negatively charged static surfaces and discharge them.

When the trigger is released, the polarity of the high voltage reverses, and negatively charged ions are produced. One operation of the trigger therefore ensures that both positive and negative static charges are eliminated. The unit is suitable for discharging surfaces in the order of one square foot in area. It should be remembered however that if static is being continually generated, the discharged surface will need to be treated with the anti-static pistol at frequent intervals.

In some circumstances, an electrically conductive floor mat may be the answer. A range of Westat mats are available from Wescorp Europe Ltd.

Anti-static foams and fluids

There are also available a variety of anti-static foams and fluids which, when applied to a highly insulating surface such as Perspex, provide a conductive film. These preparations are particularly effective if they can be applied so that they also link up with an earthed section of equipment, and thereby provide a direct leakage path for the static. One such product is an anti-static foam aerosol from R. S. Components and from Wescorp Europe Ltd.

Static meter

A pocket-size battery-operated meter unit for detecting and measuring static electricity is manufactured by Technotrend Ltd. The unit uses LEDs to indicate the strength and polarity of static charges as low as 50-V per cm. ($100).

ANTI-VIBRATION PADS AND MOUNTS

It is often necessary to ensure that precision instruments, such as carat balances, are isolated from vibration. This isolation can either be introduced at the source of the vibration, where this is practical, or at the instrument itself in cases where the vibration is being transmitted through the building structure, (or when it emanates from sources too large to isolate).

A range of cellular anti-vibration pads (trade name 'Fabcel'), suitable for isolating equipment from high-frequency vibration, is manufactured by Fabreeka Products Co Inc (UK Agent, Fabco Ltd). Cork composition sheets of various thicknesses, bearing the trade name 'Tico', are also effective against high-frequency vibrations. This product is marketed by James Walker & Co Ltd.

To guard against a wider range of vibration frequencies use can be made of the composite anti-vibration mountings manufactured by Delaney Galley Ltd. These are provided in size ranges which are related to the weight of the instrument to be isolated.

FILTERS

The filters available from Gemmological Instruments Ltd (listed individually in the appropriate chapters) are as follows:

Chance 0X7 SW U-V glass filter 50 × 50 mm.

Chance 0X1 LW U-V glass filter 50 × 50 mm.

R.G.610 red glass filter 50 × 50 mm.

Polarising filter, to fit Rayner refractometers.

Yellow monochromatic filter (590–600 nm), to fit Rayner refractometers.

Polarising, U-V, visible light and I-R filters are also available from several other sources. The following is a summary of these filters, listed under types (addresses are given in Appendix A).

Polarising filters

A wide range of linear and circular Polaroid filters is available from H. S. B. Meakin Ltd. The plastic versions are available in thicknesses of 0.38 to 0.9 mm (0.015–0.035 in.) and in sheets of 485 × 1270 mm (19 × 50 in.). Some sheets have their polarising axis parallel to the short edge, some parallel to the long edge and some at 45° to the edge. Round glass mounted Polaroids are also available in diameters from 25 to 100 mm.

Kodak 'Pola' screen is a polarising filter medium manufactured in sheet form which is physically similar to the Kodak 'Wratten' filters. The filters are marked to indicate their polarising axis. They absorb ultra-violet light, and freely transmit infra-red without polarisation. They are also available from Polarizers (UK) Ltd.

Ultra-violet filters

A range of 25 mm (1 in.) diameter U-V, and narrow-band U-V, filters is available from International Light Inc. Chance glass LW and SW U-V filters, cut to any size, can be obtained from Precision Optical Instruments (Fulham) Ltd.

Kodak 'Wratten' filters 18A and 18B are, in effect, broadband U-V filters which stop all visible light. They are used mainly in the photography of fluorescent phenomena and in U-V and I-R flash photography. Filter 12 is a minus blue complementary of deep yellow colour which absorbs ultra-violet and some blue.

Visible light filters

These, including neutral density filters, are obtainable from the suppliers listed under U-V filters. Kodak provide a complete range of 'Wratten' monochromatic filters covering the visible range from 420 nm to 670 nm.

Of particular interest are the 'colour separation sets' of which 25 (red), 58 (green) and 47B (deep blue) are perhaps the most useful.

All the Kodak range of 'Wratten' gelatine filters can be obtained cemented between glasses having diameters from 20.6 to 114.3 mm.

Infra-red filters

Precision Optical Instruments (Fulham) Ltd, stock the range of Chance 'heat' filter glasses (HA6), which can be cut to size.

Kodak manufacture four visually opaque I-R filters, Nos 87, 87C, 88A and 88B) covering various sectors of the I-R band. Number 87 is the most useful for work with infra-red light-emitting diodes with an output wavelength of 930 nm (as used in relative reflectivity meters, see Chapter 6).

Interference filters

A wide range of U-V, visible and infra-red interference filters is available from Oriel Scientific Ltd. U-V, visible and infra-red interference filters are also manufactured by OCL Inc.

MATERIALS

A very versatile and useful material is the twin-pack hard-setting putty marketed under the trade name of Bicaseal by BICC Ltd. The putty is supplied in one pound boxes which contain a pack of white and a pack of red putty. When these two putties are mixed together in equal proportions and then allowed to set for 1–2 hours, they form a hard machinable solid which can be filed, drilled and sawn.

The putty has very good adhesion properties to metal surfaces, and while still pliable, its surface can be worked to a fine finish.

Standard microscope slides and lenses, mirrors, etc., for experimental purposes can be obtained from Broadhurst Clarkson & Co Ltd. A range of plastic lenses is available from Combined Optical Industries Ltd.

Supplies of all chemical reagents and solvents, together with the heavy liquids bromoform, monobromonaphthalene and methylene iodide can be obtained in 250 mL bottles from BDH Chemicals Ltd (the heavy liquids can also be obtained in these quantities, as well as in smaller sizes, from Gemmological Instruments Ltd).

Clear Perspex diamond boxes, with open tops, are available from Mica Corfield Ltd. The boxes are made in multiples of one inch cubes, the smallest being 1 × 1 × 1 in., the next size 2 × 1 × 1 in. deep, and so on (see *Figure 16.15*).

One-inch cube plastic boxes, with lids containing an integral 2× lens are available from Hirsh Jacobson Merchandising Co. Ltd. These boxes are particularly suitable for use with micromount mineral specimens.

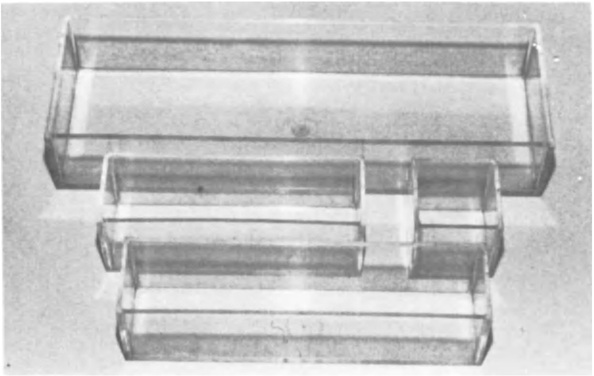


Figure 16.15
A selection from the range made by Mica Corfield Ltd of clear perspex boxes

Catalogues

Any book on commercial test instruments eventually becomes incomplete as new models are introduced year by year. One way to keep abreast of new developments in gemmological instruments is to read the professional journals and jewellery trade magazines. Another good indication of the range of equipment available can be obtained from the annual catalogues issued by the following organisations (see Appendix A for addresses).

Charles Cooper (Hatton Garden) Ltd.
Eickhorst
Gem Instruments Corporation
Gemmological Instruments Ltd.
Hanneman Lapidary Specialties
Hans-Günter Schneider
Krüss
Rubin and Son
H. S. Walsh and Sons Ltd.

References

1. Read, P. G., 'Report on the Gem Diamond Pen', *Journal of Gemmology* (July 1979).
2. Trigg, R. C., *Identi-print,* AGA Publication (January 1982)

Appendix A Manufacturers and Suppliers

Gemmological Associations/Institutes

Asociacion Espanola de Gemologia,
Paseo de Gracia, 64, Barcelona-7, Spain.

Association Francaise de Gemmologie,
17 Rue Cadet, 75009, Paris 9, France.

Canadian Gemmological Association,
Box 1106, Station Q, Toronto, Ontario M4T 2PZ, Canada.

Deutsche Gemmologische Gesellschaft,
Postfach 2260, D-6580, Idar-Oberstein 2, Germany.

Erste Österreichische Gemmologische Gesellschaft,
Graben 12, 1010 Vienna, Austria.

Gemological Institute of America,
P.O. Box 2110, Santa Monica, CA 90406, USA.

Gemmological Association of Australia (Victoria Branch),
GPO Box 5133 AA, Melbourne 5001, Victoria, Australia.

Gemmological Association of Great Britain,
Saint Dunstan's House, Carey Lane, London, EC2V 8AB, UK.

Gemmological Association of Hong Kong,
University of Hong Kong, Department of Physics, Hong Kong.

Gemmological Association of All Japan,
Tokyo Bihokaikan, 1–24 Akashi-cho, Chuo-ku, Tokyo, Japan.

Gemmological Association of Switzerland,
Multergasse 20, Ch-9000, St. Gallen, Switzerland.

Gemmologist's Association of Sri Lanka,
63 Bristol Buildings, York Street, Colombo 1, Sri Lanka.

Gemmological Institute of India,
29/30 Gurukul Chambers, 187/9 Mumbaderi Road, Bombay 1, India.

Instituto Gemologico Espanol,
Victor Hugo, 1, 3, Madrid-4, Spain.

Instituto-Gemmologico Italiano,
20146 Milano, Piazzale Gambara 7/8, Italy.

Norwegian Gemmological Association,
Dronningsgatan 27, Oslo, Norway.

Societe Belge de Gemmologie,
Rue du Midi 118, Brussels 1000, Belgium.

Smithsonian Institution,
(National Museum of Natural History), Washington, DC 20560, USA.

Manufacturers or supplies

AIGS (Asian Institute of Gemological Science),
Suite 1110-A, 606 South Hill Street, Los Angeles, CA 90014, USA.
987 Silom Road, Rama Jewelry Building, Bangkok-5, Thailand.

U. A. Aldinger,
7000 Stuttgart-1, Lenbachstrasse 1, West Germany.

P. W. Allen & Co,
253 Liverpool Road, London N1 1NA, UK.

American Optical,
Scientific Instrument Division, Southbridge, MA 01550, USA.

Auriema Ltd,
442 Bath Road, Slough SL1 68B, Buckinghamshire, UK.

Charles Austin Pumps Ltd,
100 Royston Road, Byfleet, Weybridge, Surrey KT14 7PS, UK.

Baird & Tatlock (London) Ltd,
PO Box 1, Romford RM1 1HA, UK.

Bausch & Lomb UK Ltd,
Highway House, Tattenham Crescent, Epsom Downs, Surrey T18 5BR, UK.

Ealing Beck Ltd,
Greycaine Road, Watford, Hertfordshire WD2 4PW, UK.

BDH Chemicals Ltd, Freshwater Road, Chadwell Heath, Dagenham, Essex, RM8 1RZ, UK.

Beckman Instruments Ltd,
Queensgate, Glenrothes, Fyfe KY7 5PU, Scotland, UK.

Behr Manufacturing Inc,
PO Box 831, West Bend, W1 53095, USA.

BICC General Cables Ltd,
Helsby Works, Helsby, Warrington, Cheshire WA6 0DJ, UK.

Broadhurst, Clarkson & Co. Ltd,
63 Farringdon Road, London EC1, UK.

Capital UE Ltd,
12 Tulip Tree Avenue, Kenilworth, Warwickshire, UK.

Ceres Electronics Corporation,
411 Waverley Oaks Park, Waltham, MA 02154, USA.

Combined Optical Industries Ltd,
200 Bath Road, Slough SL1 4DW, Berkshire, UK.

Charles Cooper (Hatton Garden) Ltd,
Knights House, 23–27 Hatton Wall, London EC1N 8JJ, UK.

Culti Corporation,
2–5–9 Miyakojimahondori, Miyakojima-ku, Osaka, 534 Japan.

Daneng Gem Ltd, Lyons Crescent, Tonbridge, Kent, TN9 1EY, UK.

Davenport & Waterhouse Instrument Enterprises,
PO Box 48–060, Auckland-7, New Zealand.

Dawe Instruments Ltd,
Concord Road, Western Avenue, London W3 0SD, UK.

Decon Laboratories Ltd,
Ellen Street, Portslade, Brighton, Sussex BN4 1EQ, UK.

Decon Ultrasonics Ltd,
Conway Street, Hove, Sussex BN3 3LY, UK.

Delaney Gallay Ltd,
Edgware Road, Cricklewood, London NW2, UK.

Donegan Optical Company Ltd,
Kansas City, Missouri, USA.

Eickhorst & Co,
D-2000 Hamburg 76, Hans-Henny-Jahnn-Weg 21, West Germany.

European Instruments,
80–82 Desborough Road, High Wycombe, Buckinghamshire HP11 2PR, UK.

Fabco Ltd,
Chasetown Industrial Estate, Chasetown, Staffordshire, UK.

Fabreeka Products Co. Inc,
1190 Adams Street, Boston, Mass., USA.

Finlay Microvision Co. Ltd,
12/13 Market Hill, Southam, Leamington Spa, Warwickshire, UK.

A. Gallenkamp & Co. Ltd, (agents for Olympus and Mettler),
PO Box 290, Technico House, Christopher Street, London EC2P 2ER, UK.

Gemgold International,
27 Queen Street East, Suite 703, Toronto, Ontario M5C 1R5, Canada.
Gemini GmbH, (Okuda agents)
Mannheimer Strasse 40, D-6550, Bad Kreuznach, West Germany.

Gem Instruments Corporation,
2912 Colorado Avenue, PO Box 2147, Santa Monica, CA 90406, USA.

Gem Laboratory Inc,
PO Box 212, Rego Park, NY 11375, USA.

Gemmological Instruments Ltd,
St. Dunstan's House, Carey Lane, London EC2V 8AB, UK.

Gemological Products Corporation (AIGS),
5613 Corryne Place, Culver City, CA90230, USA.

GemPhot GmbH,
Postfach 01, D-8702 Uettigen, West Germany.

Gemprint Ltd,
29 East Madison Street, Chicago, Illinois 606202, USA.

Gemtronics Australia Pty Ltd,
PO Box 105, Chermside, Queensland, Australia 4032.

Gemtek Gemmological Instruments,
33 St George's Street, London W1R 9FA, UK.

Geshiro & Co. Ltd,
Hommachi Business Bldg, 7Fl, Hommachi 2–25, Higashi-ku, Osaka 541, Japan.

GfD (Gesellschaft für Diamantgutachten mbH),
Zerrennerstrasse 36, 7530 Pforzheim, West Germany.

Glenjoy Lapidary Supplies,
19–21 Sun Lane, Wakefield, West Yorkshire, WF1 1JD, UK.

Gunson's Sortex (Mineral and Automation) Ltd,
Hyde Industrial Estate, The Hyde, London NW9 6PX, UK.

Gottl. Haigis,
Postfach 116, 7470 Albstadt 3, (Onstmettingen), Schwabstrasse 70/72, West Germany.

Hanneman Lapidary Specialties,
PO Box 2453, Castro Valley, CA 94546, USA.

Hauni South Manufacturing (Pty) Ltd,
PO Box 175, 10 Dorsetshire Street, Paarden Eiland 7405, Cape Town, Republic of South Africa.

Hirsch Jacobson Merchandising Co. Ltd,
91 Marylebone High Street, London W1, UK.

A. Hodkinson,
2 Hillview Drive, Clarkston, Glasgow, Scotland, UK.

Huddestone Gemmology Consultants Ltd,
Suite 217, The Hatton Garden Centre, 100 Hatton Garden, London EC1N 8NX, UK.

Independent Gemstone Testing Laboratory,
Suite 119, The Hatton Garden Centre, 100 Hatton Garden, London EC1N 8NX, UK.

International Light Inc,
Dexter Industrial Green, Newburyport, MA 01950, USA.

IVA Engineering Co. Ltd,
Winchfield Lodge, Winchfield, Hartley Wintney, Hampshire, UK.

Jenoptik Jena GmbH, (see also Carl Zeiss Jena Ltd.),
69 Jena, Carl-Zeiss-Strasse 1, East Germany.

Kalnew Optical Industrial Co Ltd,
250 Tokimata Iida City, Nagano-ken (399–25), Japan.

Kashan Inc,
PO Box 3318, Austin, Texas 78764, USA.

Kern & Son,
D-7470 Albstadt 1, Ebingen, West Germany.

Kodak Limited,
PO Box 114, 246 High Holborn, London WC1V 7EA, UK.

A. Krüss Optical Works,
Postfach 605265, 2000 Hamburg 60, Gertigstrasse 31, West Germany.

R. Lary Kuehn Inc,
PO Box 12252, Dallas, Texas 75225, USA.

Labimex Foreign Trade Enterprise,
Krakowskie Przedmiescie 79, 00–079 Warsaw, Poland.

E. Leitz (Instruments) Ltd, (agents for Wild Heebrugg Ltd.),
48 Park Street, Luton LU1 3HP, UK.

Ernst Leitz Wetzlar GmbH,
Postfach 2020, D-6330 Wetzlar, West Germany.

3M United Kingdom Ltd,
3M House, Wigmore Street, London W1A 1ET, UK.

Martin Precision Instruments Inc,
PO Box 829, Saratoga, CA 95070, USA.

McCrone Research Associates Ltd,
2 McCrone Mews, Belsize Lane, London NW3 5BG, UK.

Metallurgical Services Laboratories Ltd, (agents for Olympus),
Reliant Works, Brockham, Betchworth, Surrey, UK.

Mettler Instruments AG, (see also agents A.Gallenkamp & Co. Ltd),
CH-8606 Greifensee-Zurich, Switzerland.

Mettler-Waagen GmbH,
D-63 Giessen 2, Postfach 2840, West Germany.

Mettler Instrumenten, BV,
Postbus 68, Arnhem, Holland.

Mettler Instrument Corporation,
Box 100, Princeton, NJ 08540, USA.

Mica Corfield Ltd,
33 Holmethorpe Avenue, Holmethorpe Trading Estate, Redhill, Surrey, UK.

Micro-Instruments (Oxford) Ltd, (agents for Labimex),
7 Little Clarendon Street, Oxford OX1 2HP, UK.

Neill Tools Ltd, (Moore & Wright agents),
Napier Street, Sheffield S11 8HB, UK.

Nihon Hoseki-Kizai Co. Ltd,
Ohno Building, 17 Matsunaga-Cho, Kanda, Chiyoda-ku, Tokyo, Japan.

Nuclide Corporation, AGV Division,
916 Main Street, Acton, MA 01720, USA.

OCL Inc,
2789 Griffen House, Santa Rosa, CA 95402, USA.
621 London Road, High Wycombe, Buckinghamshire, HP11 1ET, UK.

Okuda Jewelry Technical Institute Co. Ltd,
2–14–10, Sangenjaya, Setagaya-ku, Tokyo 154, Japan.

Olympus Optical Co. (Europa) GmbH,
Postfach 104908, 2000 Hamburg 1, West Germany.

Olympus Optical Co. Ltd,
San-Ei Building, 22-2, Nishi Shinjuku 1-chome, Shinjuku-ku, Tokyo, Japan.

Optical Coatings Ltd,
621 London Road, High Wycombe, Buckinghamshire HP11 1ET, UK.

Oriel GmbH,
Im Tiefen See 58, D-6100 Darmstadt, West Germany.

Oriel Scientific Ltd,
PO Box 136, Kingston-upon-Thames, Surrey KT2 6SW, UK.

Orme Scientific Ltd,
PO Box 3, Stakehill Industrial Estate, Middleton, Manchester M24 2RH, UK.

Orwin Products Ltd,
4 Station Way, High Street, Epsom, Surrey, UK.

Partech Electronics Ltd,
St. Austell, Cornwall, UK.

PBL International Inc,
PO Box 108, Newburyport, MA 01950, USA.

Pike, Frank,
58g Hatton Garden, London EC1, UK.

Polarisers (UK) Ltd,
Cressex Estate, Lincoln Road, High Wycombe, Buckinghamshire, UK.

Portescap UK Ltd,
204 Elgar Road, Reading, RG2 0DD, UK.

Portescap,
2300 La Chaux-de-Fonds, 165 rue Numa-Droz, Switzerland.

Precision Optical Instruments (Fulham) Ltd,
158 Fulham Palace Road, London W6, UK.

Presidium Diamond PTE Ltd,
Suites 1001/1002 Wellington Building, 20 Bideford Road, Singapore 0922.

Prior Scientific Instruments Ltd,
London Road, Bishops Stortford, Hertfordshire, CM23 5NB, UK.

Rayner Optical Company Ltd,
17 Lorna Road, Hove, East Sussex BN3 3EP, UK.

RS Components Ltd,
PO Box 427, 13–17 Epworth Street, London EC2P 2HA, UK.

Rubin & Son PVBA,
Rubin House, Pelikaanstraat 94–96, B-2000, Antwerp, Belgium.

Sartorius Instruments (UK) Ltd,
18 Avenue Road, Belmont, Surrey, UK.

Sartorius-Werke GmbH,
Postfach 19, D-3400, Göttingen 1, West Germany.

Sauter KG, (see also agents European Instruments),
Postfach 250, D-7470 Albstadt 1, Ebingen, West Germany.

Hans-Günter Schneider,
658 Idar-Oberstein 2, Postfach 2645, Dietzenstrasse 41, West Germany.

Spectronics Corporation,
956 Brush Hollow Road, PO Box 483, Westbury, New York 11590, USA.

Starna Ltd,
33 Station Road, Chadwell Heath, Romford, Essex, UK.

Technotrend Ltd,
The Town House, High Street, Chobham, Surrey GU25 8AF, UK.

Trans-American,
11 Wallace Street, Elmwood Park, NJ 07407, USA.

Ultra-Violet Products Inc,
San Gabriel, CA 91778, USA.

Ultra-Violet Products Ltd,
Cambridge Science Park, Milton Road, Cambridge CB4 4BN, UK.

Vickers Instruments,
Haxby Road, York YO3 7SD, UK.

Volpi AG,
CH-8902 Urdorf, Bernstrasse 129, Switzerland.

H. S. Walsh & Sons Ltd,
243 Beckenham Road, Beckenham, Kent BR3 4TS, UK.

D. Walters,
18 Victoria Crescent, Tottenham, London N15 5LR, UK.

Wescorp Europe Ltd,
39A Boulevard, Weston-Super-Mare, Avon, BS23 1PG, UK.

Wild Heerbrugg Ltd, (see also agents E. Leitz (Instruments) Ltd.),
CH-9435, Heerbrugg, Switzerland.

Wood Brother Glass Co. Ltd,
Borough Flint Glass Works, Barnsley, South Yorkshire, S71 1HL, UK.

Carl Zeiss Jena Ltd, (see also Jenoptik Jena GmbH),
PO Box 43, 2 Elstree Way, Boreham Wood, Hertfordshire WD6 1NH, UK.

Carl Zeiss GmbH,
7082 Oberkochen, Postfach 35/36, Wurttenburg, West Germany.

Carl Zeiss (Oberkochen) Ltd,
Degenhardt House, 31–36 Foley Street, London W1P 8AP, UK.

Zerostat Ltd,
Eddison Road, Industrial Estate, St. Ives, Huntingdon, Cambridgeshire, UK.

Appendix B

Gemstone Constants

(in alphabetical order of gemstones)

Gemstone	*Crystal System*	*Approx. R.I.*	*D.R.*	*Dispersion*	*S.G.*	*H.*
Alexandrite – see Chrysoberyl						
Almandine (Garnet)	Cubic	1.77–1.81	–	0.027	3.8–4.2	7.5
Amazonite (Feldspar)	Triclinic	1.53–1.54	0.008	0.012	2.56	6.0
Amber	Amorphous	1.54	–	–	1.05–1.10	2.5
Andalusite	Orthorhombic	1.63–1.64	0.01	0.016	3.18	7.5
Andradite (Demantoid, Melanite, Topazolite-Garnet)	Cubic	1.89	–	0.057	3.85	6.5
Apatite	Hexagonal	1.63–1.64	0.003	0.013	3.18–3.22	5.0
Aquamarine – see Beryl						
Aventurine (Feldspar)	Triclinic	1.53–1.54	0.009	–	2.64	6.0
Benitoite	Trigonal	1.76–1.80	0.047	0.04	3.65–3.68	6.5
Beryl (Aquamarine, Emerald, Goshenite, Heliodor)	Hexagonal	1.57–1.58	0.006	0.014	2.71	7.5–8.0
Bowenite	Monoclinic	1.56	*	–	2.58	4.0
Chalcedony	Trigonal	1.53–1.54	*	–	2.58–2.64	6.5
Chrysoberyl (Alexandrite, Cymophane)	Orthorhombic	1.74–1.75	0.009	0.014	3.72	8.5
Coral	Trigonal	–	*	–	2.6–2.7	3.5
Cordierite – see Iolite						
Corundum (Ruby, Sapphire)	Trigonal	1.76–1.77	0.008	0.018	4.0	9.0
Cubic zirconium oxide	Cubic	2.16–2.18	–	0.06	5.7–6.0	8.5
Cymophane – see Chrysoberyl						
Danburite	Orthorhombic	1.63–1.64	0.006	0.016	3.0	7.0
Demantoid – see Andradite						

Diamond	Cubic	2.42	–	0.044	3.52	10.0
Dichroite – see Iolite						
Emerald – see Beryl						
Enstatite	Orthorhombic	1.66–1.67	0.01	–	3.25–3.30	5.5
Feldspar – see Amazonite, Moonstone, Oligoclase, Sunstone						
Fluorspar	Cubic	1.43	–	0.007	3.18	4.0
Garnet - see Almandine, Andradite, Grossular, Pyrope, Spessartite, Uvarovite						
GGG	Cubic	1.97	–	0.045	7.05	6.0
Goshenite – see Beryl						
Grossular (Hessonite-Garnet)	Cubic	1.74	–	0.027	3.65	6.5
Haematite	Trigonal	2.94–3.22	0.28	–	4.9–5.3	5.5–6.5
Heliodor – see Beryl						
Hessonite – see Grossular						
Hiddenite – see Spodumene						
Idocrase	Tetragonal	1.70–1.72	0.005	0.019	3.32–3.42	6.5
Iolite (Cordierite, Dichroite)	Orthorhombic	1.54–1.55	0.008	0.017	2.57–2.61	7.5
Ivory (dentine)	Organic	1.54	–	–	1.7–2.0	2.0–3.0
Ivory (vegetable)	Amorphous	1.54	–	–	1.38–1.54	2.5
Jadeite	Monoclinic	1.65–1.67	*	–	3.3	7.0
Jet	Amorphous	1.66	–	–	1.3	3.5
Kornerupine	Orthorhombic	1.67–1.68	0.013	0.018	3.28–3.35	6.5
Kunzite – see Spodumene						
Lapis Lazuli	–	1.50	–	–	2.8	5.5
Lithium Niobate	Trigonal	2.21–2.30	0.09	0.120	4.64	5.5
Malachite	Monoclinic	1.66–1.91	0.25	–	3.8	4.0
Melanite – see Andradite						
Moldavite	Amorphous	1.50	–	–	2.53	5.5
Moonstone – see Orthoclase						
Morganite (Beryl)	Hexagonal	1.58–1.59	0.008	0.014	2.85	7.5–8.0
Nephrite	Monoclinic	1.61	*	–	3.0	6.0
Obsidian	Amorphous	1.50	–	–	2.4	5.0
Oligoclase (Feldspar)	Triclinic	1.53–1.54	0.007	–	2.64	6.0

Gemstone	*Crystal System*	*Approx. R.I.*	*D.R.*	*Dispersion*	*S.G.*	*H.*
Opal	Amorphous	1.45	–	–	2.1	6.0
Orthorclase (Feldspar)	Monoclinic	1.52–1.53	0.006	–	2.57	6.0
Pearl	Orthorhombic	1.52–1.66	–	–	2.71–2.74	3.5–4.0
Peridot	Orthorhombic	1.65–1.69	0.038	0.02	3.34	6.5
Phenakite	Trigonal	1.65–1.67	0.016	0.015	2.95–2.97	7.5
Pyrite	Cubic	–	–	–	4.84–5.10	6.5
Pyrope (Garnet)	Cubic	1.75–1.77	–	0.022	3.7–3.8	7.5
Quartz	Trigonal	1.54–1.55	0.009	0.013	2.65	7.0
Rhodonite	Triclinic	1.73–1.74	0.014	–	3.6–3.7	6.0
Rhodochrosite	Trigonal	1.60–1.82	0.22	–	3.5–3.6	4.0
Ruby – see Corundum						
Rutile	Tetragonal	2.61–2.90	0.287	0.28	4.2–4.3	6.5
Sapphire – see Corundum						
Scapolite (blue)	Tetragonal	1.54–1.55	0.009	0.017	2.60–2.71	6.0
Scapolite (pink, yellow)	Tetragonal	1.56–1.58	0.02	0.017	2.60–2.71	6.0
Sinhalite	Orthorhombic	1.67–1.71	0.038	0.018	3.48	6.5
Smithsonite	Trigonal	1.62–1.85	0.23	–	4.30	5.0
Soapstone – see Steatite						
Sodalite	Cubic	1.48	–	–	2.28	5.5–6.0
Spessartite (Garnet)	Cubic	1.80	–	0.027	4.16	7.0
Sphene – see Titanite						
Spinel (natural)	Cubic	1.717	–	0.020	3.60	8.0
Spinel (synthetic)	Cubic	1.727	–	0.020	3.64	8.0
Spodumene (Hiddenite, Kunzite)	Monoclinic	1.66–1.68	0.015	0.017	3.18	7.0
Steatite (Soapstone)	Monoclinic	1.54–1.59	0.05	–	2.5–2.8	1.0+
Strontium Titanate	Cubic	2.41	–	0.19	5.13	5.5
Sunstone (Feldspar)	Triclinic	1.53–1.54	0.009	–	2.64	6.0
Tanzanite – see Zoisite						
Titanite (Sphene)	Monoclinic	1.89–2.02	0.13	0.051	3.53	5.5
Topaz (white/blue)	Orthorhombic	1.61–1.62	0.01	0.014	3.56	8.0

Topaz (brown/yellow)	Orthorhombic	1.63–1.64	0.008	0.014	3.53	8.0
Topazolite – see Andradite						
Tourmaline	Trigonal	1.62–1.64	0.018	0.017	3.01–3.11	7.0
Turquoise	Triclinic	1.61–1.65	*	–	2.6–2.8	6.0
Uvarovite (Garnet)	Cubic	1.87	–	–	3.77	7.5
YAG	Cubic	1.83	–	0.028	4.58	8.5
Zoisite (Tanzanite – blue Zoisite)	Orthorhombic	1.69–1.70	0.009	–	3.35	6.5
Zircon (normal)	Tetragonal	1.93–1.99	0.058	0.039	4.68	7.25
Zircon (low)	Amorphous	1.78–1.84	–	–	3.9–4.1	6.0
Zirconia – see Cubic Zirconium Oxide)						

* Crypto-crystalline

Gemstone constants

(in order of refractive indices)

Approx. R.I.	*D.R.*	*Gemstone*	*Crystal System*	*Dispersion*	*S.G.*	*H.*
1.43	–	Fluorspar	Cubic	0.007	3.18	4.0
1.45	–	Opal	Amorphous	–	2.1	6.0
1.48	–	Sodalite	Cubic	–	2.28	5.5–6.0
1.50	–	Lapis Lazuli	–	–	2.8	5.5
1.50	–	Obsidian	Amorphous	–	2.4	5.0
1.50	–	Moldavite	Amorphous	–	2.53	5.5
1.52–1.53	0.006	Orthoclase (Feldspar)	Monoclinic	–	2.57	6.0
1.52–1.66	–	Pearl	Orthorhombic	–	2.71–2.74	3.5–4.0
1.53–1.54	0.008	Amazonite (Feldspar)	Triclinic	0.012	2.56	6.0
1.53–1.54	*	Chalcedony	Trigonal	–	2.58–2.64	6.5
1.53–1.54	0.007	Oligoclase (Feldspar)	Triclinic	–	2.64	6.0

Approx. R.I.	*D.R.*	*Gemstone*	*Crystal System*	*Dispersion*	*S.G.*	*H.*
1.53–1.54	0.009	Sunstone (Feldspar)	Triclinic	–	2.64	6.0
1.53–1.54	0.009	Aventurine (Feldspar)	Triclinic	–	2.64	6.0
1.54	–	Amber	Amorphous	–	1.05–1.10	2.5
1.54	–	Ivory (dentine)	Amorphous	–	1.7–2.0	2.0–3.0
1.54	–	Ivory (vegetable)	Amorphous	–	1.38–1.54	2.5
1.54–1.55	0.008	Iolite (Cordierite, Dichroite)	Orthorhombic	0.017	2.57–2.61	7.5
1.54–1.55	0.009	Quartz	Trigonal	0.013	2.65	7.0
1.54–1.55	0.009	Scapolite (blue)	Tetragonal	0.017	2.60–2.71	6.0
1.54–1.59	0.05	Steatite (Soapstone)	Monoclinic	–	2.50–2.80	1.0+
1.56	*	Bowenite	Monoclinic	–	2.58	4.0
1.56–1.58	0.02	Scapolite (pink/yellow)	Tetragonal	0.017	2.60–2.71	6.0
1.57–1.58	0.006	Beryl (Aquamarine, Emerald, Goshenite, Heliodor)	Hexagonal	0.014	2.71	7.5–8.0
1.58–1.59	0.008	Morganite (Beryl)	Hexagonal	0.014	2.85	7.5–8.0
1.60–1.82	0.22	Rhodochrosite	Trigonal	–	3.5–3.6	
1.61	*	Nephrite	Monoclinic	–	3.0	6.0
1.61–1.62	0.01	Topaz (white/blue)	Orthorhombic	0.014	3.56	8.0
1.61–1.65	*	Turquoise	Triclinic	–	2.6–2.8	6.0
1.62–1.64	0.018	Tourmaline	Trigonal	0.017	3.01–3.11	7.0
1.62–1.85	0.23	Smithsonite	Trigonal	–	4.3	5.0
1.63–1.64	0.01	Andalusite	Orthorhombic	0.016	3.18	7.5
1.63–1.64	0.003	Apatite	Hexagonal	0.013	3.18–3.22	5.0
1.63–1.64	0.006	Danburite	Orthorhombic	0.016	3.0	7.0
1.63–1.64	0.008	Topaz (brown/yellow)	Orthorhombic	0.014	3.53	8.0
1.65–1.67	0.016	Phenakite	Trigonal	0.015	2.95–2.97	7.5
1.65–1.67	*	Jadeite	Monoclinic	–	3.3	7.0
1.65–1.69	0.038	Peridot	Orthorhombic	0.02	3.34	6.5
1.66	–	Jet	Amorphous	–	1.3	3.5
1.66–1.67	0.01	Enstatite	Orthorhombic	–	3.25–3.30	5.5

1.66–1.68	0.015	Spondumene (Kunzite, Hiddenite)	Monoclinic	0.017	3.18	7.0
1.66–1.91	0.25	Malachite	Monoclinic	–	3.8	4.0
1.67–1.68	0.013	Kornerupine	Orthorhombic	0.018	3.28–3.35	6.5
1.67–1.71	0.038	Sinhalite	Orthorhombic	0.018	3.48	6.5
1.69–1.70	0.009	Zoisite	Orthorhombic	–	3.35	6.5
1.70–1.72	0.005	Idocrase	Tetragonal	0.019	3.32–3.42	6.5
1.717	–	Spinel (natural)	Cubic	0.020	3.6	8.0
1.727	–	Spinel (synthetic)	Cubic	0.020	3.64	8.0
1.73–1.74	0.014	Rhodonite	Triclinic	–	3.6–3.7	6.0
1.74	–	Grossular (Hessonite-Garnet)	Cubic	0.027	3.65	6.5
1.74–1.75	0.009	Chrysoberyl (Alexandrite, Cymophane)	Orthorhombic	0.014	3.72	8.5
1.75–1.77	–	Pyrope (Garnet)	Cubic	0.022	3.7–3.8	7.5
1.76–1.77	0.008	Corundum (Ruby, Sapphire)	Trigonal	0.018	4.0	9.0
1.76–1.80	0.047	Benitoite	Trigonal	0.04	3.65–3.68	6.5
1.77–1.81	–	Almandine (Garnet)	Cubic	0.027	3.8–4.2	7.5
1.78–1.84	–	Zircon (low)	Amorphous	–	3.9–4.1	6.0
1.80	–	Spessartite (Garnet)	Cubic	0.027	4.16	7.0
1.83	–	YAG	Cubic	0.028	4.58	8.5
1.87	–	Uvarovite	Cubic	–	3.77	7.5
1.89	–	Andradite (Demantoid, Melanite, Topazolite-Garnet)	Cubic	0.057	3.85	6.5
1.89–2.02	0.13	Titanite (Sphene)	Monoclinic	0.051	3.53	5.5
1.93–1.99	0.058	Zircon (normal)	Tetragonal	0.039	4.68	7.25
1.97	–	GGG	Cubic	0.045	7.05	6.0
2.16–2.18	–	Cubic Zirconium Oxide	Cubic	0.06	5.7–6.0	8.5
2.21–2.30	0.09	Lithium Niobate	Trigonal	0.120	4.64	5.5
2.41	–	Strontium Titanate	Cubic	0.19	5.13	5.5
2.42	–	Diamond	Cubic	0.044	3.52	10.0
2.61–2.90	0.287	Rutile	Tetragonal	0.28	4.2–4.3	6.5
2.94–3.22	0.28	Haematite	Trigonal	–	4.9–5.3	5.5–6.5

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*Crypto-crystalline

Gemstone constants

(in order of specific gravities)

S.G.	*Gemstone*	*Crystal System*	*Approx. R.I.*	*D.R.*	*Dispersion*	*H.*
1.05–1.10	Amber	Amorphous	1.54	–	–	2.5
1.3	Jet	Amorphous	1.66	–	–	3.5
1.38–1.54	Ivory (vegetable)	Amorphous	1.54	–	–	3.5
1.7–2.0	Ivory (dentine)	Amorphous	1.54	–	–	2.0–3.0
2.1	Opal	Amorphous	1.45	–	–	6.0
2.28	Sodalite	Cubic	1.48	–	–	5.5–6.0
2.4	Obsidian	Amorphous	1.50	–	–	5.0
2.5–2.8	Steatite (Soapstone)	Monoclinic	1.54–1.59	0.05	–	1.0+
2.53	Moldavite	Amorphous	1.50	–	–	5.5
2.56	Amazonite (Feldspar)	Triclinic	1.53–1.54	0.008	0.012	6.0
2.57	Orthoclase (Feldspar)	Monoclinic	1.52–1.53	0.006	–	6.0
2.57–2.61	Iolite (Cordierite, Dichroite)	Orthorhombic	1.54–1.55	0.008	0.017	7.5
2.58	Bowenite	Monoclinic	1.56	*	–	4.0
2.58–2.64	Chalcedony	Trigonal	1.53–1.54	*	–	6.5
2.6–2.7	Coral	Trigonal	–	*	–	3.5
2.6–2.71	Scapolite (blue)	Tetragonal	1.54–1.55	0.009	0.017	6.0
2.6–2.71	Scapolite (pink/yellow)	Tetragonal	1.56–1.58	0.02	0.017	6.0
2.6–2.8	Turquoise	Triclinic	1.61–1.65	*	–	6.0
2.64	Oligoclase (Feldspar)	Triclinic	1.53–1.54	0.007	–	6.0
2.64	Sunstone (Feldspar)	Triclinic	1.53–1.54	0.009	–	6.0
2.64	Aventurine (Feldspar)	Triclinic	1.53–1.54	0.009	–	6.0
2.65	Quartz	Trigonal	1.54–1.55	0.009	0.013	7.0
2.71	Beryl (Aquamarine, Emerald, Goshenite, Heliodor)	Hexagonal	1.57–1.58	0.006	0.014	7.5–8.0
2.71–2.74	Pearl	Orthorhombic	1.52–1.66	–	–	3.5–4.0
2.8	Lapis Lazuli	–	1.50	–	–	5.5

2.85	Morganite	Hexagonal	1.58–1.59	0.008	0.014	7.5–8.0
2.95	Phenakite	Trigonal	1.65–1.67	0.016	0.015	7.5
3.0	Danburite	Orthorhombic	1.63–1.64	0.006	0.016	7.0
3.0	Nephrite	Monoclinic	1.61	*	–	6.0
3.01–3.11	Tourmaline	Trigonal	1.62–1.64	0.018	0.017	7.0
3.18	Andalusite	Orthorhombic	1.63–1.64	0.01	0.016	7.5
3.18	Fluorspar	Cubic	1.43	–	0.007	4.0
3.18	Spodumene (Hiddenite, Kunzite)	Monoclinic	1.66–1.68	0.015	0.017	7.0
3.18–3.22	Apatite	Hexagonal	1.63–1.64	0.003	0.013	5.0
3.25–3.30	Enstatite	Orthorhombic	1.66–1.67	0.01	–	5.5
3.28–3.35	Kornerupine	Orthorhombic	1.67–1.68	0.013	0.018	6.5
3.3	Jadeite	Monoclinic	1.65–1.67	*	–	7.0
3.32–3.42	Idocrase	Tetragonal	1.70–1.72	0.005	0.019	6.5
3.34	Peridot	Orthorhombic	1.65–1.69	0.038	0.02	6.5
3.35	Zoisite (Tanzanite)	Orthorhombic	1.69–1.70	0.009	–	6.5
3.48	Sinhalite	Orthorhombic	1.67–1.71	0.038	0.018	6.5
3.5–3.6	Rhodochrosite	Trigonal	1.60–1.82	0.22	–	4.0
3.52	Diamond	Cubic	2.42	–	0.044	10.0
3.53	Titanite (Sphene)	Monoclinic	1.89–2.02	0.13	0.051	5.5
3.53	Topaz (brown/yellow)	Orthorhombic	1.63–1.64	0.008	0.014	8.0
3.56	Topaz (white/blue)	Orthorhombic	1.61–1.62	0.01	0.014	8.0
3.6–3.7	Rhodonite	Triclinic	1.73–1.74	0.014	–	6.0
3.6	Spinel (natural)	Cubic	1.717	–	0.02	8.0
3.64	Spinel (synthetic)	Cubic	1.727	–	0.02	8.0
3.65	Grossular (Hessonite-Garnet)	Cubic	1.74	–	0.027	6.5
3.65	Benitoite	Trigonal	1.76–1.80	0.047	0.04	6.5
3.7–3.8	Pyrope (Garnet)	Cubic	1.75–1.77	–	0.022	7.5
3.72	Chrysoberyl (Alexandrite, Cymophane)	Orthorhombic	1.74–1.75	0.009	0.014	8.5
3.77	Uvarovite	Cubic	1.87	–	–	7.5
3.8	Malachite	Monoclinic	1.66–1.91	0.25	–	4.0
3.8–4.2	Almandine (Garnet)	Cubic	1.77–1.81	–	0.027	7.5
3.85	Andradite (Demantoid, Melanite, Topazolite-Garnet)	Cubic	1.89	–	0.057	6.5

S.G.	*Gemstone*	*Crystal System*	*Approx. R.I.*	*D.R.*	*Dispersion*	*H.*
3.9–4.1	Zircon (low)	Amorphous	1.78–1.84	–	–	6.0
4.0	Corundum (Ruby, Sapphire)	Trigonal	1.76–1.77	0.008	0.018	9.0
4.16	Spessartite (Garnet)	Cubic	1.80	–	0.027	7.0
4.2–4.3	Rutile	Tetragonal	2.61–2.90	0.287	0.28	6.5
4.3	Smithsonite	Trigonal	1.62–1.85	0.23	–	5.0
4.58	YAG	Cubic	1.83	–	0.028	8.5
4.64	Lithium Niobate	Trigonal	2.21–2.30	0.09	0.120	5.5
4.68	Zircon (normal)	Tetragonal	1.93–1.99	0.058	0.039	7.25
4.9–5.3	Haematite	Trigonal	2.94–3.22	0.28	–	5.5–6.5
5.13	Strontium Titanate	Cubic	2.41	–	0.19	5.5
5.7–6.0	Cubic Zirconium Oxide	Cubic	2.16–2.18	–	0.06	8.5
7.05	GGG	Cubic	1.97	–	0.045	6.0

*Crypto-crystalline

Inclusions in natural gemstones

Ruby	*Burma* – Calcite, zircon, spinel, rutile (star and silk). 'Treacle' swirls of colour. *Thailand* – Less inclusions than Burma. Garnet common – round opaque crystals surrounded by liquid feathers. Can be positively identified from Burma and Sri Lankan rubies by complete lack of fluorescence under X-rays (killed by iron). *Sri Lanka* – Diffuse silk. Zircon crystals and 'haloes'.
Sapphire	*Burma* – Healing cracks (looking like crumpled flags). Short thick rutile needles. *Thailand* – Never includes any rutile. Crystals of Plagioclase Feldspar. *Sri Lanka* – Liquid feathers. Long thin rutile needles (long silk). Zircon crystals and 'haloes'. Three-phase inclusions. Chains of spinel crystals. *Kashmir* – Cloudiness caused by series of very fine fissures. *Montana* – Hexagonal crystals surrounded by liquid crystals.
Emerald	*Brazil* – Biotite mica. Thin liquid films resembling paving stones. *Colombia* – (Chivor and Muzo mines) – Three-phase inclusions. *India* – Two-phase inclusions resembling commas. *Pakistan* – Paving stone pattern of liquid inclusions. Phenakite crystals. *USSR* (Siberia) – Actinolite crystals in blade form. *Zimbabwe (Sandewana)* – Tremolite fibres. Transvaal mica.
Garnet	*Pyrope* – Zircon crystal and 'haloes'. *Almandine* – Crossed needles of hornblende. Apatite. Rutile (giving star effect). Zircon crystals with 'haloes'. *Hessonite* – Profuse Diopside crystals of good shape. 'Treacle'. *Demantoid* – Byssolite asbestos fibres forming 'horsetails'. *Spessartite* – Liquid shreds.
Aquamarine	Negative crystals (liquid filled). Flags (liquid patches), more often seen in green Beryl. 'Rain'. Two-phase inclusions.
Topaz	Liquid filled cavities containing immiscible liquids. Interference colours generated by internal cleavages. Two-phase inclusions and three-phase inclusions.

Peridot	*Hawaii* – Liquid discs looking like water lillies. *Arizona* – Long liquid bubbles. *Isle of St John* – Magnetite octahedra.
Spinel	Spinel octahedra in Burma reds (forming ghost-like feather). Spinel crystals in Sri Lankan stones – arranged in chains.
Tourmaline	Tourmaline crystals. Liquid filled cavities. Profuse 'negative' crystals. Actinolite crystals.
Zircon	Zircon inclusions (low green zircons have colour zones or paralleled fine lines).
Amethyst	'Tiger Stripe' structure.
Moonstone	Stress cracks looking like centipedes.
Quartz	Rutile needles.

Inclusions in synthetic gemstones

Synthetic Quartz – Blue, green and yellow quartz grown from a seed crystal by the hydrothermal method may show the colourless seed inside.

Vanadium Emerald – (Hydrothermal process). Colour banding. No chromium lines. Spectral band in orange.

Lechleitner Emerald – (Thin layer deposited by hydrothermal process on a piece of poor quality beryl). Discontinuity of inclusions between overgrowth and seed. Network of cracks. Parts of rear facets left unpolished to preserve colour.

Chatham, Gilson and Zerfass Emerald – (Flux-melt process). Veil-like feathers.

Corundum – (Flame-fusion process). Curved colour bands (most marked in blue sapphire). Dichroism often shows through table facet instead of through girdle as with natural gem. Flask or tadpole shaped bubbles. Clouds of very fine particles (unmelted power). Curved growth lines (prominent in ruby, weaker in sapphires and not seen at all in yellow sapphire).

Spinel – (Flame-fusion process). Patches of light and dark (due to strain) when viewed through polariscope. Curved growth lines and bubbles are only seen in red spinel.

Strontium Titanate – (Flame-fusion process). Tiny centipede shaped inclusions.

Alexandrite – (Flux-melt process). Swarms of tiny inclusions. Banding or growth lines. Paralleled negative crystals.

Kashan Rubies – (Flux-melt process). 'Rain' and 'dust' inclusions and rod-like parallel crystals. 'Paint-splash' inclusions consisting of flux residues. Coarse solid-filled negative crystals. Very little silk.

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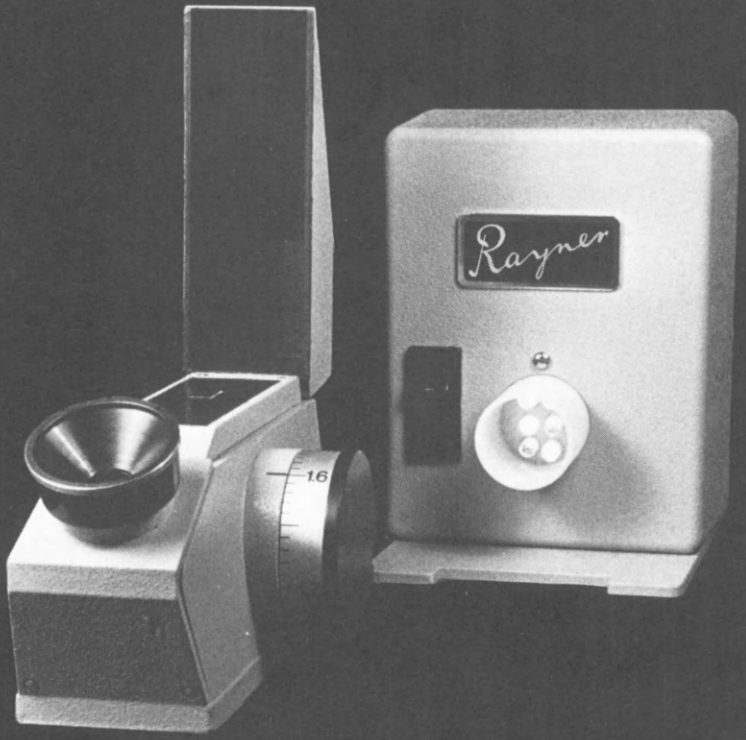
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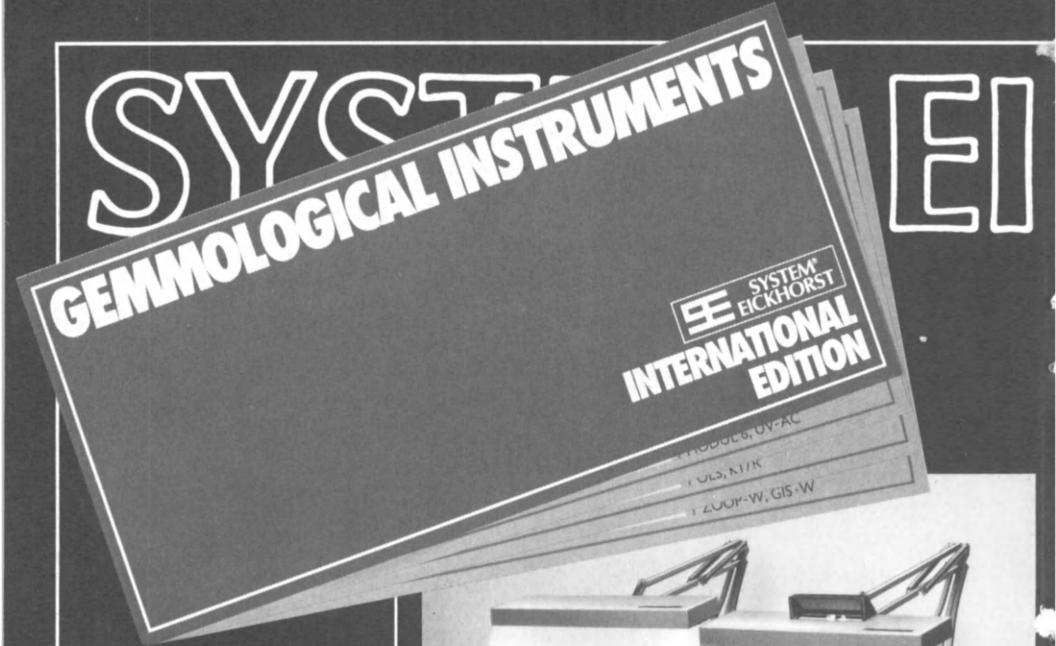

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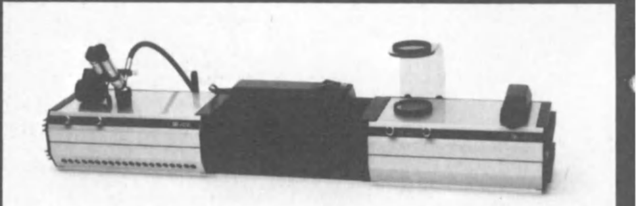
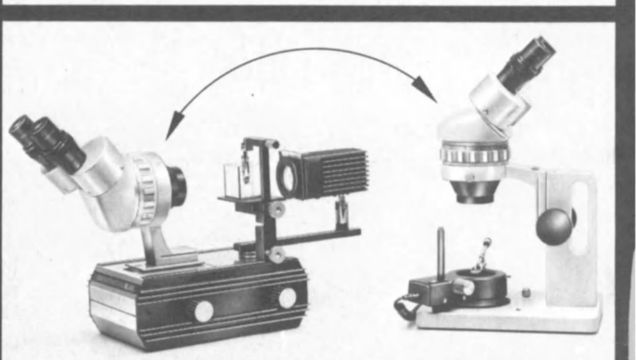
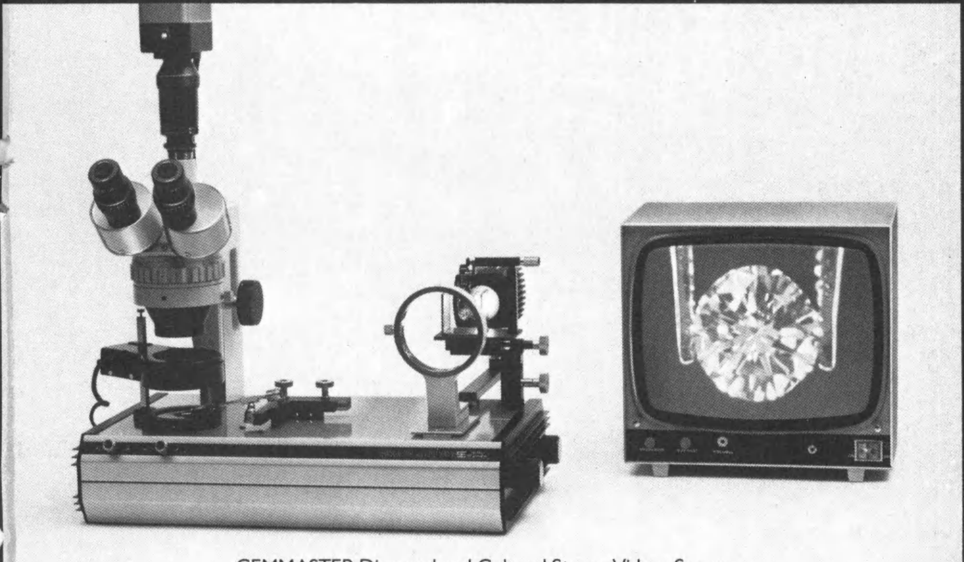


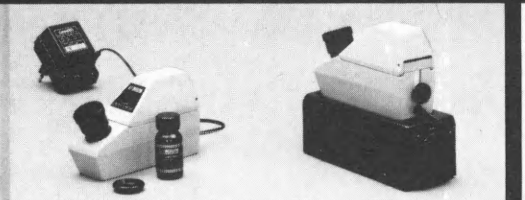
GEMMODUL Spectroscope, UV-Lamp, Polariscope, Refractometer



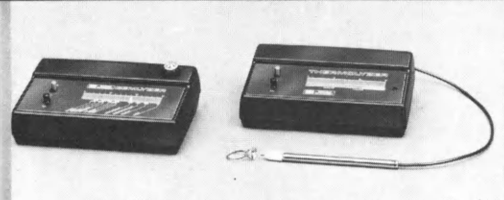
GEMMOSCOPE Modular Gemmological Microscope System



GEMMASTER Diamond and Colored Stones Video-Scope



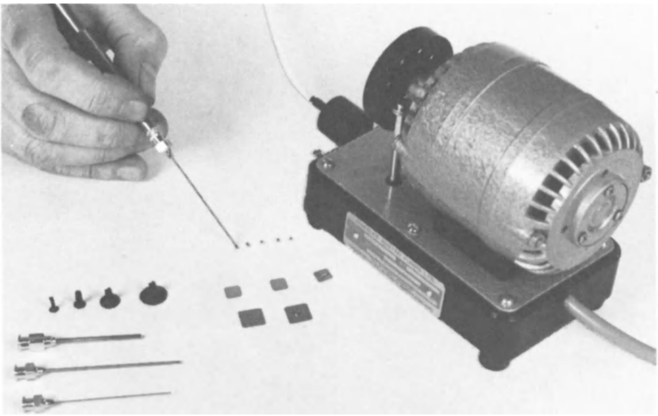
GemLED Refract. & built-in 589 nm LED Illum.



GEMLYZER · THERMOLYZER

VVS-Scope Fibre Optical Darkfield Illumination


DIAMOND COLOR CHECKER
DC-530A



MARTIN MGA-1 GEM ANALYZER

CLASSIFY GEM STONES IN SECONDS

METHOD OF OPERATION

The Analyzer measures the index of refraction by means of a precisely controlled infrared light beam directed at the sample gem stone. The reflected light is analyzed electronically and interpreted on the direct-reading meter scale. The measurement is performed with a filtered infrared wavelength where the indices of refraction are most unique, and where ambient light has little effect on the readings.

FEATURES

DIRECT READING . . . Gem stones are identified by name, without converting a numerical value.

FLEXIBILITY . . . The analyzing port has been especially designed to accommodate stones over half carat, including those MOUNTED in a setting.

FACTORY CALIBRATED . . . There is no need to adjust the instrument. The electronics have been tested and sealed against moisture and are designed to work efficiently in a wide variety of climatic conditions. 0°C to 55°C, 0% to 95% humidity.

COMPACT DESIGN . . . The analyzer is lightweight at only 21 oz. and can be conventiently carried. Dimensions are 165 mm x 108 mm x 44 mm.

SOLID STATE ELECTRONICS . . . All electronic components are of the highest quality. The equivalent of over 100 components are integrated into a specially designed circuit to insure trouble-free, accurate performance.

REGULATED POWER SOURCE . . . The power from the 9 volt battery is precisely regulated to assure an accurate analysis and long battery life – units tested have given the equivalent of over 100 readings a day for one year!

LIMITATIONS

Certain gem stones have been perfectly and economically synthesized. These stones are Emerald, Spinel, Ruby, Sapphire, Alexandrite, etc. Because these synthesized stones have the same chemical composition as their counterparts found in nature, the MGA-1 cannot discriminate between them.

Since the index of refraction is one of many characteristics measured to identify gem stones, further tests and judgment should be employed to be absolutely certain of a gem stone's identity. Martin Precision Instruments, its manufacturer or its agents shall in no way be liable for damages relating to incorrect identification caused by instrumentation misuse or defect.

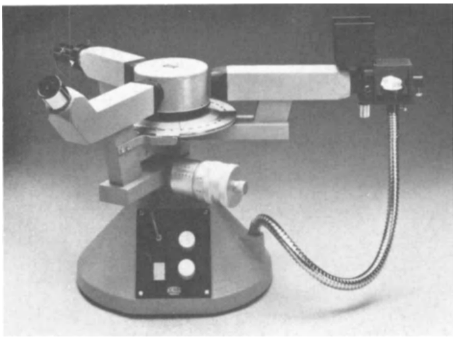
LOW COST

THE MARTIN GEM ANALYZER can be purchased for $400.00. A handsomely styled carrying case is also available for $18.00. All prices are F.O.B. Mountain View, California. Prices subject to change without notice.

Mail order, or inquiries to:

MARTIN PRECISION INSTRUMENT COMPANY •
P.O. Box 829, Saratoga, CA 95070, U.S.A. Tel: (408) 867-7597

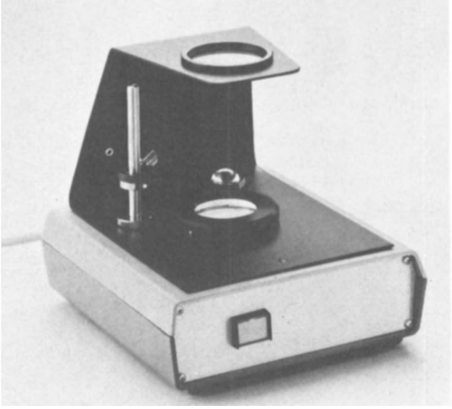
THIS IS OUR 10th YEAR IN BUSINESS



KL 1301
Gem Spectroscope for universal Application
In its general construction, this spectroscope is similar to the traditional Kirchhoff and Bunsen type. It is used for the purity observation and measurement of absorption spectra. The equipment includes two gem holders. Well-surveyable wavelength scale of the 400-700nm range. Achromatic lenses 30mm diameter, Lineary dispersion C-F, within distinct 28mm visual distance, built-in coldlight source, precision slot with fine adjustment, available with comprehensive accessories for expansion to goniometer and spectrometer.

KL7
Gem Spectroscope
Used for specific emerald determination, with adjustable, light-proof sealing slot.

ER 601 / BM 611 ER 602 / BM 610
Gem Refractometer, provided with Illumination Base
Simple and convenient handling.
Refraction index:nD = 1.3 - 1.81.
Refraction index:nD 1.79 - 2.21



PK 10 / KN 10
Polariscope with Konoscope
The polariscope is a very handy modern-design unit with built-in illumination.

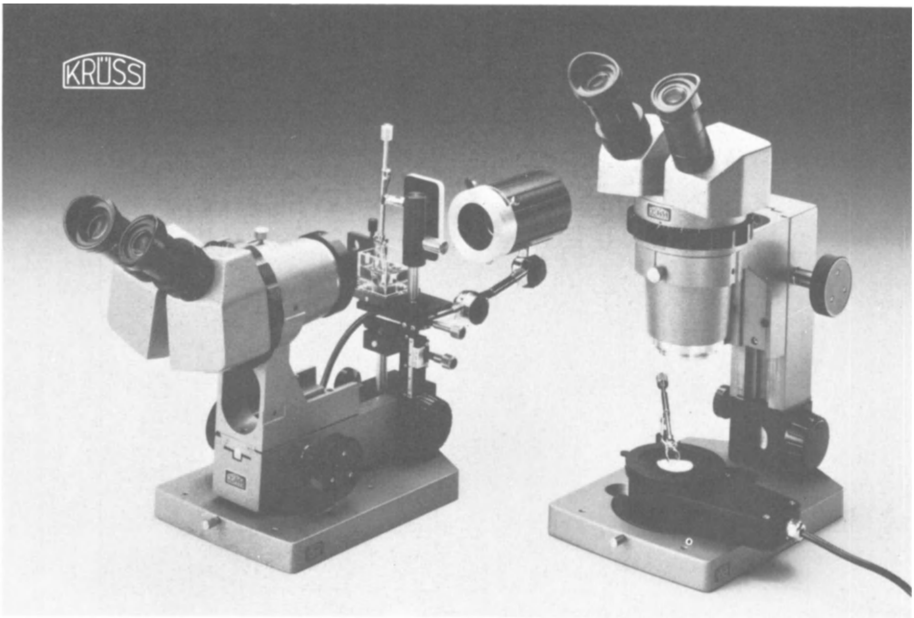
KRÜSS

A. KRÜSS

D-2000 Hamburg 60
Postfach 605265
West Germany
Tel: 040/273635 + 2701148
Telex: 2174898 krue d

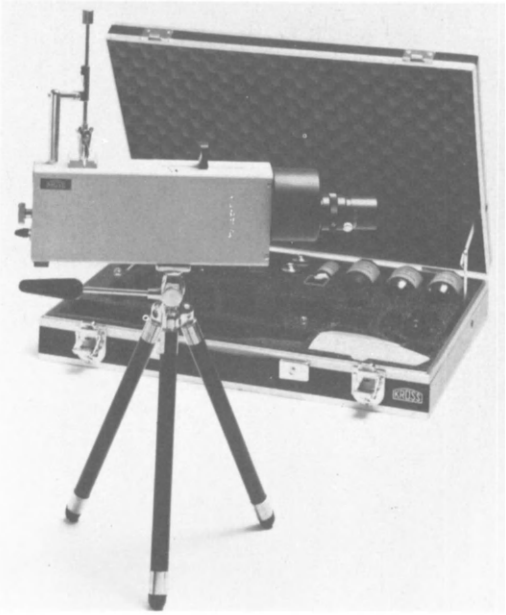
Werkstätten für Optik Feinmechanik und Elektronik GmbH

Our full promotional brochure on Gemmological instruments available on request



KA 11
Gem Diamond Stereo Microscope

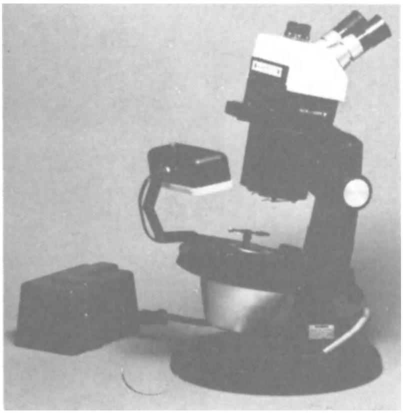
Featuring 10x to 40x magnification attainable with zoom optics. 160x magnification can be reached with auxiliary ocular and lens, especially well suited for work in the vertical and horizontal plane. Main application of this top value microscope of the renowned KA-Series is emerald determination and diamond grading. When in horizontal position, the emerald can be conveniently examined when immersed in the immersion liquid. By simple manipulation the microscope can be set to the vertical position and used in similar manner as the KA 6 Z microscope. With this type of microscope the space requirements of ordinarily two units are successfully combined and reduced to the space requirement of one single unit. This rather inexpensive solution eliminates also the need of two separate tripods.

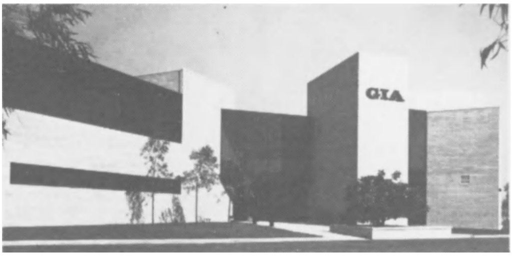


KA 4 KRS
Gemmler Travel-Case Laboratory

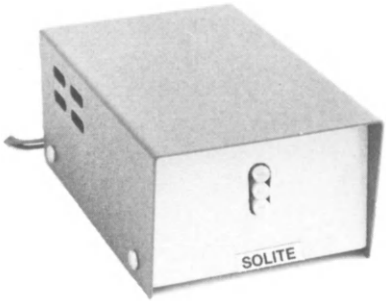
Facilitates the mobile service of a gem laboratory. Complete equipment in metal frame reinforced travelling case. All parts easily accessible.

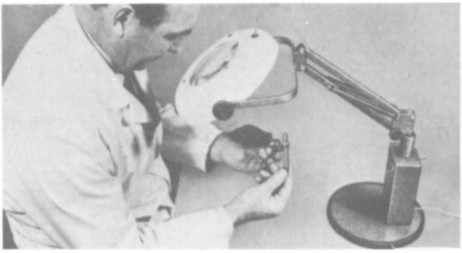
American Optical
PORTALAB
GEMOLOGICAL LABORATORY
OFF
HIGH
LIGHT FIELD
DARK FIELD
INTENSITY CONTROL
FIBEROPTIC ILLUMINATOR
ULTRAVIOLET UNIT
LONGWAVE

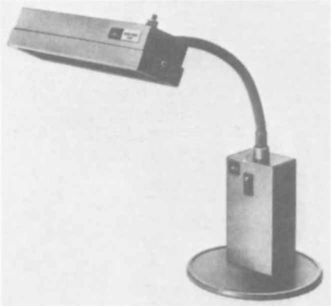



GIA


START TEST
FINISH TEST
DAVENPORT & WATERHOUSE
INSTRUMENTS LTD
Auckland New Zealand


SOLITE





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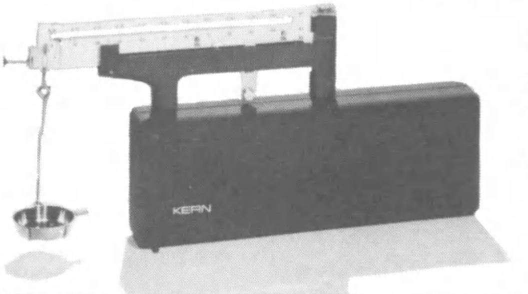
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