CHAPTER 1
INTRODUCTION

1.1 The Need for Digital Image Processing techniques in the identification of Original diamonds from Cubic Zirconia

Digital image processing and analysis techniques are used today in a variety of problems. Many application oriented image analyzers are available and are working satisfactorily in real environment. The following are a few major application areas [1].

1. Office automation: Optical character recognition; document processing; cursive script recognition; logo and icon recognition; identification of address area on envelop.

2. Industrial automation: Automatic inspection system; non-destructive testing; automatic assembling; robotics; oil and natural gas exploration; seismography; process control applications.

3. Bio-medical: Electrocardiogram (ECG), Electroencephalogram (EEG), Electromyogram (EMG) analysis; cytological, histological and stereological applications; automated radiology and pathology; X-ray image analysis; mass screening of medical images such as chromosome slides for detection of various diseases, mammograms, cancer smears; tomographic images; routine screening of plant samples; 3D (3 dimensional) reconstruction and analysis.

4. Remote sensing: Natural resources survey and management; estimation related to agriculture, hydrology, forestry, mineralogy; urban planning; environment and pollution control; cartography, registration of satellite images with terrain maps; monitoring traffic along roads, docks and airfields.

5. Scientific applications: High energy physics; bubble chamber and other forms of track analysis.

6. Criminology: Finger print identification; human face registration and matching; forensic investigation.

7. Astronomy and space applications: Restoration of images suffering from geometric and photometric distortions; computing close-up picture of planetary surfaces.
8. Meteorology: Short-term weather forecasting, long-term climatic change detection from satellite and other remote sensing data; cloud pattern analysis; etc.

9. Information technology: Facsimile image transmission, videotex; videoconferencing and videophones.

10. Entertainment and consumer electronics: HDTV (High Definition Television); multimedia and video-editing.

11. Printing and graphic arts: Color fidelity in desktop publishing; art conservation and dissemination.

12. Military applications: Missile guidance and detection; target identification; navigation of pilotless vehicle; reconnaissance; and range finding.

In addition to the above mentioned areas, another important application area of image processing techniques is gemology. The survey of literature shows that there is no nondestructive, easily affordable, economical, reliable, universal systematic method available for identifying original diamonds from Cubic Zirconia. Hence, the most important objective of the current work is to apply digital image processing techniques to yet another area, 'Gemology', for the purpose of differentiating / identifying original diamonds from Cubic Zirconia using scanned images of the gemstones of these two varieties. This work seems to be a novel and innovative approach involving digital image processing techniques in the identification or distinguishing original diamonds from Cubic Zirconia. Both sellers as well as buyers of diamonds can use the methods described in this thesis to find out whether the gem bought or sold is original diamond or not, without any special skills, but with only little practice to work with computers.

1.1.1 The Diamond

Diamond is known to mankind from prehistoric times and has been prized for centuries as a gemstone of exceptional beauty, brilliance and lustre. The word diamond derives its name from the alteration of the Latin word 'adamas' meaning 'untamable' or 'unconquerable', referring to its hardness [2]. Diamonds are more than unsurpassed beauty and sparkle. In no other gemstones are so many desirable attributes combined [3]. A diamond is likely the oldest thing anyone can ever own, probably 3 billion years in age, two thirds the age of the Earth [4]. Today diamond symbolizes wealth, durability, status, and peerless quality. Across time and cultures, diamond has also been associated with invulnerability, lightning, magic,
healing, protection, and poisoning. "Diamond" comes from the Greek adamao, transliterated as "adamao", "I tame" or "I subdue". The adjective "adamas" was used to describe the hardest substance known, and eventually became synonymous with diamond. It is difficult to determine at what point in history the hardest known substance become diamond. "Adamas" may have previously referred to the next hardest mineral, corundum – the gem variety is sapphire – or to something else altogether. Tracing the history of diamond is complicated by this problem with names [5]. Until 1725, India was the major source of diamonds. It is astonishing to note that in the list of world’s most famous diamonds, majority find their source originating in India. The supreme beauty of Diamonds, their priceless rarity, purity and durability makes them the perfect symbol of a man’s love for his partner. Used for centuries as an expression of love and marriage, Diamonds are the ultimate gift [6].

The hardest, rarest, densest natural substance known to man, diamonds have been a source of fascination (and misinformation) since 800 BC when they were first presented to royalty in India [7, 3]. The cutting of diamonds into the complex faceted forms is actually a relatively recent practice. For centuries, rough diamonds were kept as talismans, and often not worn at all, though natural octahedral (eight-sided stones) were sometimes set in rings. A Hungarian queen’s crown set with uncut diamonds, dating from approximately 1074, is perhaps the earliest example of diamond jewellery. The royalty of France and England wore diamonds by the 1300’s. In sixteenth century England, fashionable lovers etched romantic pledges on window – panes with the points of their diamond rings, known as “scribbling rings”.

The earliest record of diamond — polishing (with diamond powder) is Indian, and probably dates from the fourteenth century [5]. There are also contemporary references to the practice of diamond polishing in Venice. The earliest reference to diamond cutting is in 1550 in Antwerp, the most important diamond center of the period, where a diamond — cutters' guild was soon to be established.

Some of the greatest and famous diamonds in the world are Star of Africa, Excelsior, Orloff, Taylor-Burton, Koh-i-Nur, Hope Diamond, Millennium Star, Heart of Eternity and Centenary. Figure 1.1 shows some of the greatest diamonds.
Figure 1.1 Some of the greatest diamonds.
Carbon – the element known from prehistoric time, derive its name from Latin ‘carbo’ meaning charcoal. Carbon is known as the king of elements owing to its versatility and diversity in all fields, which is unquestionable. It is widely distributed in Nature, from molecules of life to matter in outer cosmos. It holds the sixth place in the list of abundance in Universe. The biochemical mechanism responsible for life is very much dependent on the role of carbon either directly, or otherwise. In 1772, Antoine Lavoisier realized the allotropic forms of carbon by a famous experiment in which he found that burning a piece of diamond and a charcoal of equal mass yields the same amount of Carbon Dioxide which made him conclude that charcoal and diamond are indeed made up of the same element carbon [2].

Diamond is a polymorph (many forms) of the element carbon [8]. Diamonds are elemental carbon formed from pure carbon. Ironically the other form of pure carbon is graphite, which is very soft with a soapy feel and a dull gray color. Graphite is commonly the “lead” in a pencil. Mohs Hardness Scale of minerals starts at 1(talc) and ranges to 10(diamond). That does not mean that diamonds are ten times harder than talc; mineral number 9 on the Mohs scale is Corundum, a class of minerals which includes rubies and sapphires. Diamonds can be from ten to hundreds times harder than Corundum. Diamonds themselves vary in hardness; for example, stones from Australia are harder than those found in South Africa.

Diamonds, in their perfect cubic crystal form, occur as isolated octahedral (eight-sided) crystals. Many variations on the cubic form are found in nature, including twelve-sided crystals and a flattened triangular shape known as a macle. Figure 1.2 shows the size comparison of octahedral diamond crystal for 1 to 500 carats.

Gemologists recognize three main varieties of diamonds: ordinary, bort, and carbonado [9]. Ordinary diamonds occur as crystals often with rounded faces, from colorless and free from flaws to stones of variable color and full of flaws. Bort diamonds occur in rounded forms without a good crystal structure. They are generally of inferior quality as a gemstone. Carbonados are black opaque diamonds. They are crystalline but do not possess the mineral cleavage found in ordinary diamonds. Diamonds form in nature only under the extreme conditions found in the upper mantle at depths of 150 to 200 kilometers (possibly down to 300 kilometers): pressures of greater than 50 kilobars (50,000 x normal atmospheric pressure) and temperatures of 900 to 1,300°C and possibly higher. Diamonds are formed at depths
of 150 to 200 kilometers in the upper mantle and are brought to the surface in a peculiar igneous rock called kimberlite (named after the diamond-bearing region of Kimberly, South Africa where these rocks were first identified). Kimberlites are intrusive bodies that originate in the upper mantle and are injected upward through the upper mantle and the lower and upper crust, eventually reaching the earth's surface as a small volcanic complex.

![Diamond Crystal Size Comparison](image)

**Figure 1.2** Size comparison of octahedral diamond crystal for 1 to 500 carats.

Diamond is distinguished from all other precious stones no less by its chemical composition than by its unique physical characters, for no other gem consists of a single element. It is pure crystallized carbon (C). Its substance is therefore identical chemically with the material of graphite and charcoal. The extraordinary difference in the appearance of diamond and that of other forms of carbon depends solely on the crystallization of the material and the physical characters consequent on this. The fact that the one and only constituent of diamond is pure carbon was already known at the end of the eighteenth century, and was suspected even earlier than this. In the year 1675 Sir Isaac Newton had arrived at the conclusion that diamond must be combustible, this conclusion, though correct in itself, was based on theoretical grounds, now known to be mistaken, connected with the high refractive index of the substance. In 1694-5, the Academicians, Averani and Targioni, at the instigation of the Grand Duke Cosmos III of Tuscany, conducted
research, on the combustibility of diamond at the "Accademia del Cimento" of Florence. Diamonds were exposed to the intense heat of a fierce charcoal fire or were placed in the focus of a large burning-glass. A stone so treated did not fuse but gradually decreased in size and finally disappeared, leaving behind no appreciable amount of residue [10]. These experiments proved that the substance of diamond, as such, is destroyed at a high temperature, whether its disappearance was due simply to volatilization, as in the case of ammoniac, was of course undecided at that early date.

In diamond, each carbon atom is covalently single bonded to four other carbon atoms. The impeccable qualities of the diamond arise from the elemental nature of carbon and its bonding structure. In crystals with the diamond, each atom is surrounded tetrahedrally by four other atoms. Each atom has four near neighbors, which are arranged about it at the corners of a regular tetrahedron [11], as shown in figure 1.3.

![Figure 1.3 The arrangement of the carbon atoms in the diamond crystal](image)

While the rock in which diamonds are found may be 50 to 1,600 million years old, the diamonds themselves are approximately 3.3 billion years old. Diamond is made up of repeating units of carbon atoms joined to four other carbon atoms via the strongest chemical linkage, covalent bonds that create a highly symmetrical and uniform framework [12]. Each carbon atom is in a rigid tetrahedral network where it is equidistant from its neighboring carbon atoms. The structural unit of diamond consists of 8 atoms, fundamentally arranged in a cube. This network is very stable and rigid, which is why diamonds are so very hard and have a high melting point. Once diamond is formed, it will not reconvert back to graphite because the barrier is too high. Diamonds are said to be metastable, since they are kinetically rather than thermodynamically stable. Under the high pressure and temperature conditions needed to form diamond its form is actually more stable than graphite, and
so over millions of years carbonaceous deposits may slowly crystallize into diamond [13].

Diamond is the hardest natural material. The Mohs hardness scale, on which diamond is a '10' and corundum (sapphire) is a '9', doesn't adequately attest to this incredible hardness, as diamond is exponentially harder than corundum. Diamond is also the least compressible and stiffest substance. It is an exceptional thermal conductor - 4 times better than copper - which gives significance to diamonds being called 'ice'. Diamond has an extremely low thermal expansion, is chemically inert with respect to most acids and alkalis, is transparent from the far infrared through the deep ultraviolet, and is one of only a few materials with a negative work function (electron affinity). One consequence of the negative electron affinity is that diamonds repel water, but readily accept hydrocarbons such as wax or grease. Diamonds do not conduct electricity well, although some are semiconductors. Diamond can burn if subjected to a high temperature in the presence of oxygen. Diamond has a high specific gravity; it is amazingly dense given the low atomic weight of carbon. The brilliance and fire of a diamond are due to its high dispersion and high refractive index. Diamond has the highest reflectance and index of refraction of any transparent substances. Diamond gemstones are commonly clear or pale blue, but colored diamonds, called 'fancies', have been found in all the colors of the rainbow. Boron, which lends a bluish color, and nitrogen, which adds a yellow cast, are common trace impurities. Two volcanic rocks that may contain diamonds are Kimberlite and Lamproite. Diamond crystals frequently contain inclusions of other minerals, such as garnet or chromite. Many diamonds fluoresce blue to violet, sometimes strongly enough to be seen in daylight. Some blue-fluorescing diamonds phosphoresce yellow (glow in the dark in an afterglow reaction).

Type of Diamonds

The different types of diamonds are listed below.

- Natural Diamonds

  Natural diamonds are classified by the type and quantity of impurities found within them.

  - Type Ia - This is the most common type of natural diamond, containing up to 0.3% nitrogen.
o Type Ib - Very few natural diamonds are this type (~0.1%), but nearly all synthetic industrial diamonds are. Type Ib diamonds contain up to 500 ppm nitrogen.

o Type IIa - This type is very rare in nature. Type IIa diamonds contain so little nitrogen that it isn't readily detected using infrared or ultraviolet absorption methods.

o Type IIb - This type is also very rare in nature. Type IIb diamonds contain so little nitrogen (even lower than type IIa) that the crystal is a p-type semiconductor.

• Synthetic Industrial Diamonds

Synthetic industrial diamonds are produced the process of High Pressure High Temperature Synthesis (HPHT).

• Thin Film Diamonds

A process called Chemical Vapor Deposition (CVD) may be used to deposit thin films of polycrystalline diamond.

The diamond lattice and graphite lattice [14] are shown in figures 1.4 (a) and 1.4 (b) respectively.

Choose virtually any characteristic of a material - electronic, structural, or optical - and the value associated with diamond will almost always be the most extreme: Diamond is invariably 'the biggest and the best'.

A number of areas of application of diamonds are gradually beginning to appear [15]. Some of them are listed below.
* Thermal management - Natural diamond has a thermal conductivity roughly four times superior to that of copper, and it is an electrical insulator.

Cutting tools - CVD diamond is also finding applications as an abrasive and as a coating on cutting tool inserts.

* Wear Resistant Coatings - The ability to protect mechanical parts with an ultra-hard coating, in for example, gearboxes, engines, and transmissions, may allow greatly increased lifetimes of components with reduced lubrication. Intense research efforts into suitable barrier layer materials to allow diamond coating of iron and steel machine parts are currently underway.

* Optics - Because of its optical properties, diamond is beginning to find uses in optical components, particularly as protective coatings for infrared (IR) optics in harsh environments.

* Electronic devices - the possibility of doping diamond and so changing it from being an insulator into a semiconductor opens up a whole range of potential electronic applications.

* Composite Materials - Another interesting new development in diamond technology is the ability to deposit CVD diamond onto the outer surfaces of metal wires or non-metallic fibers.

Diamond is a macromolecular structure in which any one carbon atom is bonded to 4 others by relatively strong covalent bonds. [16]. Diamond is still the hardest substance known to science. But a group of American researchers say that they have produced a composite material which contains crystals of carbon nitride, a substance which scientists believe stands a good chance of being even harder.

Gems are of two kinds – mineral and organic [17]. Mineral gems are naturally created within the earth as a result of chemical reactions to heat, pressure, and chemical mixtures. Organic gems are produced by organic creatures – Pearl, Coral, Amber, Jet, Ivory and Shell being the organic gems. The criteria for making a mineral a gem or precious gem is the durability, hardness, lustre, and beauty. The most beautiful and durable tend to be the precious stones, such as Diamond, Ruby and Sapphire. These qualities are created by the chemical structure of the mineral – the shape of the crystal composition within the mineral determines its reflective quality, known as refractory indexes.
Diamond crystals

The diamond octahedron has the shape that is described as a diamond (figure 1.5). While it is the most common shape for a diamond crystal, cubes, dodecahedra, and combinations of these three shapes (figure 1.6) are common [18]. All are highly symmetrical, with equal dimensions in three perpendicular directions, and all are manifestations of the cubic crystal system to which the mineral diamond belongs.

Figure 1.5 Most Common shape of the diamond crystal – Octahedran

Figure 1.6 Other shapes of the diamond crystal

The Physics of Diamond

Diamond is an extreme material among possible atomic aggregations in nature, and as such has many extreme properties. This unique position makes it a fascinating subject both for science and for applications. This has been particularly true in recent years, since the surprising discovery at Union Carbide (1953) of the possibility of chemical vapor deposition of diamond films at low pressures, where diamond is metastable with respect to graphite. This discovery cleared the way to the development of economical deposition techniques that have been obtaining progressively better-quality diamond, both pure and doped, in a controlled way and for a variety of applications. The remarkable properties and applications range from mechanical (the extreme hardness, tensile and compressive strength, wear performance) to thermal (the highest conductivity), optical (wide range of
transparency), chemical (inertness to most chemicals), biological (biocompatibility) and electronic (high electronic carrier mobility, large band gap and dielectric breakdown strength, negative electron affinity), with the simultaneous presence of so many extraordinary qualities often resulting in added value for a given application [19]. It’s newly discovered remarkable electron affinity properties lead to a new dimension in research and development, of great strategical importance for an increasing role of diamond in electronics.

Specific gravity of Diamond

The specific gravity of diamond as determined by various observers varies between 3.3 and 3.7 g/cm³ [10]. Reliable determinations made on pure stones free from enclosures have however, in every case yielded values not lower than 3.50 and not much higher than this the mean value may, therefore, be placed at 3.52. The following are values obtained in particular instances by careful observers using pure material.

3.524 Brazilian diamond
3.524 Colorless and yellow diamond from the Cape
3.517 Brazilian diamond
3.529 “Star of the South” from Brazil
3.5213 “Florentine”
3.50 Diamond from Burrandong New South Wales
3.492 Colorless diamond from Bonieo

The fall of the last value below 3.5, is due to the attachment of a few air bubbles to the stone during the weighing in water. The small differences in the specific gravity values given above are probably due to the presence of various impurities.

Optical Properties of Diamond

Optics

When light strikes the interface between two materials, the light generally divides into two parts: reflected light (angle of incidence=angle of reflection) and refracted light [20]. There is another phenomenon called Total Internal Reflection (TIR). This is when the light ray enters the medium at its critical angle. This causes the light to bend such that it travels along the surface. Once the critical angle is exceeded, all the light gets reflected, thus no light gets refracted. This is TIR. TIR occurs only when light travels from a higher-index medium toward a lower-index
medium. Fiber-optic cables use this idea of TIR. The inside of the cable consists of glass while the outer layer is cladding. This is very practical in the field of medicine.

The refractive index of the diamond and air are 2.42 and 1.00 respectively. Consider a beam of light is propagating through a diamond and strikes a diamond-air interface at an angle of incidence of 28°. As the angle of incidence 28° is greater the critical angle 24.5°, no part of the light beam will enter the air, and the beam will be totally reflected back into the diamond.

Relatively speaking, the critical angle for the diamond-air boundary is an extremely small number. Of all the possible combinations of materials which could interface to form a boundary, the combination of diamond and air provides a large difference in the index of refraction values. This means that there will be a small critical angle. This peculiarity about the diamond-air boundary plays an important role in the brilliance of a diamond gemstone. Having a small critical angle, light has the tendency to become "trapped" inside of a diamond once it enters. A light ray will typically undergo TIR several times before finally refracting out of the diamond. Because the diamond-air boundary has such a small critical angle (due to diamond's large index of refraction), most rays approach the diamond at angles of incidence greater than the critical angle [21]. This gives diamond a tendency to sparkle. The effect can be enhanced by the cutting of a diamond gemstone with a strategically planned shape. The figure 1.7 depicts the total internal reflection within a diamond gemstone with a strategic and a non-strategic cut [21].

**TIR and the Importance of a Diamond's Cut**

[Image of diagram showing TIR and a diamond's cut]

Light entering through the top facet undergoes TIR a couple of times before finally exiting. Light entering through the top facet of the diamond quickly exits at the second boundary since its angle of incidence is less than the critical angle.

Figure 1.7 TIR and the Importance of a Diamond’s Cut
In short, the faces of the diamond are cut in such a way that a ray of light entering the crystal undergoes multiple total reflections. Inside the diamond, the ray striking the surface makes an angle of incidence always greater than 24.5° (critical angle). Due to this multiple total internal reflections taking place inside the diamond, it appears sparkling [22]. Polished diamonds rely on light for their beauty. Light brings together the inherent properties of diamond, the optical effects created by faceting, and the observer’s ability to appreciate the gemstone.

Reflection and Refraction

When light strikes the outside surface of a clean, well-polished diamond, or any other transparent material, some of that incident light is reflected (bounced) back from the surface. The remaining incident light is refracted, which means that it is transmitted (or enters) through the surface and into the diamond. This also means that some of the incident light’s energy is reflected, while the rest of the light’s energy is transmitted into the diamond. How much of that light’s energy is reflected or refracted depends on several factors: the angle at which the light strikes the surface; the optical properties of the material (in this case, diamond); the wavelength, or color, of the particular ray of light that is striking the surface; and the polarization state (direction of vibration) of that ray [23].

Reflection is light bouncing back from a surface. The angle at which light reflects from a surface is equal to the angle at which it strikes the surface. Both angles are measured from the normal which is an imaginary line perpendicular to the surface at the point where the light strikes. The law of reflection can be written as a simple mathematical equation: \( \theta_i = \theta_r \), where \( \theta_i \) stands for the angle of incidence and \( \theta_r \) stands for the angle of reflection.

Refraction is light transmitting through a surface. When a light beam passes from a material of lesser optical density, say, air to a material of greater optical density, say, diamond, that light will slow down in speed. It will also bend in direction, unless the beam strikes perpendicular to the surface; this bending is called refraction. A beam of light will bend towards the normal when entering a diamond and away from the normal when leaving a diamond. The degree to which light bends (the angle of refraction) is determined by the difference in optical density between the two media through which the light passes. This density is described by a quantity called the Refractive index (RI). By Snell’s law, if light passes between air and a medium with an RI of \( n \) : \( \sin \theta_i = n \sin \theta_r \) where \( \theta_i \) is the angle of incidence, \( \theta_r \) is the
angle of refraction and $n$ is the index of refraction. RI of diamond is 2.42. The Critical angle is formed by the maximum angle at which light will refract when entering a diamond at a given point. It defines which light beams are reflected or refracted. The higher a medium’s refractive index is, the more it bends light and the smaller its critical angle will be. Because diamond has a high refractive index, it has a small critical angle $24.5^\circ$. This is one reason why diamonds have the potential to be so brilliant.

The direction in which light will bend depends on whether that light is traveling into a medium that is of greater or lesser optical density. When light enters a diamond, which is optically denser than the air it was originally traveling through, it will bend toward the normal. Its angle of refraction will be less than its angle of incidence. However, when light leaves a diamond it bends away from the normal. In these cases, its angle of refraction is greater than its angle of incidence. Figure 1.8 shows that the angle of incidence is equal to the angle of reflection. Figure 1.9 shows the angles of incidence and refraction.

![Figure 1.8 The angle of incidence equals the angle of reflection.](image)

![Figure 1.9 Angles of incidence and refraction](image)

Dispersion

Dispersion is the scientific term for the breaking up of white light into its spectral colors [24], shown in figure 1.10. Prisms show that a beam of white light is composed of different light rays, each with its own wavelength. Each different wavelength is perceived as a different color. Each ray of light has its own wavelength, direction of travel, and intensity.
Fire

Fire is not the same as dispersion. Fire is the appearance of colored flashes (chromatic flares) [24], shown in figures 1.11 and 1.12. Fire is influenced by a diamond’s proportions in four ways:

1. The angle that light enters a diamond.
2. The angle that light exits a diamond.
3. The number of interactions (bounces) the light has inside the diamond.
4. The number of times that the light rays spread out across junctions between two adjacent facets.

Different illumination conditions and surroundings can enhance or diminish the appearance of fire. Fire is a well-recognized and appreciated appearance aspect in diamonds, and is a primary reason why people desire and treasure them. Thus, reflection, refraction, dispersion and fire are interdependent relationships that affect light’s behavior in a polished diamond, and thus can affect the diamond’s appearance.

Dispersion is an inherent property of transparent materials and is often a single value based on a material’s refractive index (RI) for all examples of the same material and composition (e.g., all polished diamonds have the same dispersion regardless of their shape or proportions). Fire, on the other hand, is an appearance aspect of polished diamonds and other gemstones. Fire is the suite of colored flashes.
that one sees when viewing a diamond. Fire varies from diamond to diamond, as well as under different lighting conditions and viewing environments. These chromatic flares have several causes. Most of these causes are found in the interdependent relationship between the optical properties of diamond as a material, the effects of a polished diamond’s cut (e.g., facet angles, the quality of a diamond’s polish), and the illumination and environment (or “panorama”) in which the diamond is viewed.

Transparency

In its pure condition diamond is most beautifully clear and transparent; the presence of enclosures of foreign matter, however, often diminishes the natural transparency of the stone, in some cases causing almost complete opacity [10]. Dark colored diamonds, especially brown and black specimens, are frequently transparent only at their edges, and black diamonds are often completely opaque. The degree of transparency depends largely on the quality known as the water of a diamond. A stone which is perfectly transparent, colorless, and free from all faults is described as a diamond of the first or purest water.

4 C’s of the Diamond

Diamonds have been prized through the ages for their beauty and rarity. How beautiful, and how rare, they are is determined by the Four C’s [25]. The 4 different factors that make up a diamond are Carat, Cut, Clarity, and Color. Carat refers to the weight of the stone, cut describes the basic shape, or shapes of the stone, clarity is a description of the imperfection(s) in the stone, and color refers to how clear to how yellowish a diamond is.

4 C’s of Diamonds – Carat

Weighing commodities as small and precious as gems demands a very small, uniform unit of weight. To meet this need, early gem traders turned to plant seeds that were reasonably uniform in size and weight. Two of the oldest were wheat grains and carob seeds. Both were common in the gem-producing and trading areas of the ancient world. Wheat was a dietary staple, and individual wheat grains provided a plentiful and relatively uniform weight standard. Diamond weights are sometimes approximated in grains. The carob, or locust tree, produces edible seed pods that are still important as feed for livestock and as a flavoring. Traders used the inedible seeds as a standard weight from which the modern metric carat evolved.

Carat weight (ct) was standardized in the early twentieth century. If a 'one-carat' diamond had been purchased in 1895, it might have weighed anywhere
from 0.95 to 1.07 metric carats, depending on where it was bought. But between 1908 and 1930, the standard metric carat was adopted throughout most of Europe and in Japan, Mexico, South Africa, Thailand, the USA, and the USSR. Consumers sometimes confuse the terms carat and karat. Although in some countries the two are synonymous, in the US, karat refers to the fineness of gold alloys and carat refers to gem weights.

This is the easiest "C" to understand. The weight of a diamond is directly related to its size, and, although incorrect, these terms are sometimes used interchangeably. The unit of weight for diamonds and other gemstones is called the carat. This is a term which comes from the ancient use of the very uniformly-sized carob seed in measuring small weights. A table of common weight-related terms is given in Table 1.1 [26]. The relationship between how large a diamond looks and its actual weight can be deceptive. For well-proportioned, round diamonds the size (diameter)-weight relationships are given in figure 1.13 (The diamond images are not actual sizes, and their proportional differences are only approximate.). As examples, a 1.00ct stone should normally be about 6.5 millimeters (mm) in diameter; a 3.00ct would be 9.3 mm.

Conversely, when a 1.00ct. round diamond is cut too deep, it appears to be of smaller size than a well-cut stone, because the diameter will be smaller than the expected 6.5mm. This means paying for extra weight in the pavilion and girdle areas, which doesn't add to the beauty of the diamond. Furthermore, the stone will often appear dark and dull in the center. Superior cut will give superior light performance producing a bright and lively stone. It may not be the biggest looking diamond on the block, but it will be the BEST looking diamond! Like most gems, diamonds are weighed in metric carats; one carat equals 0.2 gram [5]. In other words, it takes almost 142 carats to equal 1 ounce. But even this is not precise enough for something so precious. Even with relatively inexpensive diamonds, fractions of a carat can represent hundreds of dollars (thousands, with top-quality stones). For this reason, in the diamond industry, weight is measured to a thousandth of a carat and rounded to the nearest hundredth (or point).

The standard unit for designation of the weight of a diamond is the carat, which is equivalent to two hundred milligrams (1/5 gram). Table 1.1 shows carat (ct) weight and its equivalent weight.
Carat Weight | Equivalent Weight
--- | ---
One Carat | 200 milligrams = 0.200 grams (There are 5 carats in 1 gram and 142 carats in 1 ounce.)
| A carat is divided into 100 parts each called a point. So 1 carat = 100 points.
Three-Quarter Carat | 75 points
Half Carat | 50 points
Quarter Carat | 25 points
One Grain or "a one grainer" | 25 points or 1/4ct.; A diamond of approximately 1ct. would be called a 4 grainer, one ~ 1.5ct. would be a 6 grainer, and a 0.5ct. stone a 2 grainer.
Melee | Diamonds weighing less than 1/5ct. (less than 20 points). Stones of this size are set using various techniques as groupings in jewelry.

Table 1.1 Carat weight and equivalent weight

Figures 1.13 and 1.14 show the size and weight relationship for colorless, round brilliant cut, original diamonds.

Figure 1.13 Weight and size relationship [26]

<table>
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<th>1 mm</th>
<th>2 mm</th>
<th>3 mm</th>
<th>4 mm</th>
<th>5 mm</th>
<th>6 mm</th>
<th>6.5 mm</th>
<th>7 mm</th>
<th>7.5 mm</th>
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<td>0.01 Ct</td>
<td>0.03 Ct</td>
<td>0.10 Ct</td>
<td>0.25 Ct</td>
<td>0.50 Ct</td>
<td>0.75 Ct</td>
<td>1.00 Ct</td>
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<td>1.65 Ct</td>
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</table>

Figure 1.14 Size and weight relationship [6]
Tables 1.2 and 1.3 are the weight estimation charts for round brilliant cut, original diamonds.

<table>
<thead>
<tr>
<th>Size (MM)</th>
<th>Approx. Weight of Diamond</th>
<th>Number of Diamonds Per Carat</th>
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</thead>
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<td>33</td>
</tr>
<tr>
<td>2.25</td>
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</tr>
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Table 1.2 Weight Estimation Chart Round Brilliant.

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<th>Millimeter Measurement</th>
<th>Carat Weight</th>
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Table 1.3 Diamond Weight Estimation [27]

Effect of carat weight on price

Because diamonds are more rare the larger they are, the carat weight is not directly proportional to the total asking price. For example, the total price of a 2ct. colorless, internally flawless stone is not twice the total price of an identical 1ct. stone, but is more than three times the price, and an identically graded 3ct. diamond is
about 7.7-times as expensive as the 1ct. stone. Also, a premium is added to diamond prices as they reach and exceed each 1/4ct. increment in weight.

4 C's of Diamonds - Clarity

This indicates how clear the diamond is, how free from blemishes and other imperfections [25]. The terms used in Clarity grading are given below and the clarity grading is shown in figure 1.15.

- **FL** - Flawless, no inclusions or blemishes of any sort under 10X loupe (a lens that magnifies the object 10 times than its original size).
- **IF** - Internally flawless, no inclusions and only insignificant blemishes under 10X.
- **VVS1 - VVS2** - Inclusions are difficult to locate or see under 10X.
- **VS1 - VS2** - Inclusions present less difficulty to locate or see under 10X.
- **SI1 - SI2** - Inclusions are readily seen at 10X, although they remain invisible to the unaided eye when the diamond is viewed face up.
- **I1** - One or more inclusions or their effect can be seen by the unaided eye.
- **I2** - Inclusions are easily visible to the unaided eye.
- **I3** - Inclusions are so obvious and large that they affect both brilliancy and beauty of the diamond.

Clarity in diamond is a measure of the surface (blemishes) and internal (inclusions) characteristics of a polished diamond, and has, as does color, a major impact on value. Obviously, the fewer clarity characteristics a stone has, the more rare, and therefore valuable, it is. A diamond with the highest clarity grade is flawless (FL), which means it has no discernable blemishes or inclusions (when magnified 10...
times using a 10X loupe), a situation not frequently encountered. Combining this with a D (representing colorless) color in a diamond, would result in a truly rare stone. However, this combination of highest color and clarity does not guarantee a beautiful diamond. It is most importantly the quality of the CUT (in combination with the other 3C's), which releases the beauty of the stone to the eye of the beholder(s).

Clarity characteristics are an inherent part of a diamond's life, and can arise from events which occurred during its formation deep in the earth, the mining procedures used to collect it, the cutting of rough into its final shape and the wearing of the stone. The descriptions of the more important characteristics of blemishes and inclusions are given below.

**Blemishes**
- **Abrasions**: They are tiny nicks on facet junctions or the culet; caused by wear or coming in contact with other diamonds.
- **Extra Facets**: They are small facets placed to remove imperfections; not part of the cutting style.
- **Naturals**: Part of the original crystal surface remaining on the polished stone, frequently in the area of the girdle.
- **Polish Lines and Marks**: They are tiny parallel lines or surface clouding left by irregular polishing or excessive heating during polishing, respectively.
- **Rough Girdle**: It is a grainy or pitted girdle surface usually caused by poor workmanship.
- **Surface Graining**: Surface graining is due to structural irregularities in crystal growth; may appear as faint lines, causing grooved or wavy surfaces and often cross facet junctions.

**Inclusions**
- **Bearding**: Bearding means tiny feathers extending inward from a bruted girdle surface.
  (Bruting is the process of rubbing two diamonds together to achieve the rounded shape of the diamond.)
- **Cavities and Chips**: They are large / deep openings, and small / shallow openings in the diamond’s surface, respectively.
- **Clouds**: They are hazy or milky areas of many very small, usually crystalline inclusions.
* Feathers: Feathers are cleavages or fractures often white and feathery in appearance. (There are 4 cleavage planes in diamond, which run in octahedral directions.)* Fractures are breaks along planes other than cleavage planes and may alternate with them to form step-like feathers.)
* Included Crystals: They are mineral crystals, such as garnet or peridot, contained inside a diamond.
* Indented Naturals: They are natural rough surfaces that penetrate the stone and may distort the girdle outline.
* Internal Graining: They are regions of irregular crystal growth that may appear as milky or colored lines or streaks, or may be reflective.
* Laser Drill Holes: A tiny tube made by a laser; the surface opening may resemble a pit, while the tube usually resembles a needle.
* Needles: They are needle-shaped included crystals.
* Pinpoints: They are areas of minute, dot-like inclusions.
* Twinning Wisps: They are cloudy areas produced by distorted crystal growth.

4 C's of Diamonds – Color

Figure 1.16 shows grades in the color of diamonds ranging from D to Z.

![Color Grading Diagram]

Grades in the color of diamonds range from D-Z, D being truly colorless and of the highest quality. E and F are also graded as colorless while G, H, I and J are near colorless. Diamonds graded K, L, and M will have obvious hints of color and as the scale approaches P subtle changes may be found in hue and tone.
The GIA (Gemological Institute of America) Color Grading Scale [25] is shown below.

D, E, F : Colorless
G, H, I : Nearly Colorless
J, K, L : Slightly yellow
M, N, O : Light yellow
Z : Fancy colors.

In 1953, GIA created the International Diamond Grading System, which is recognized today worldwide by virtually every professional jeweler in the industry. This system rates diamonds based on the 4Cs – color, clarity, cut, and carat weight. The GIA color scale ranges from D, which is absolutely colorless, all the way to Z, which includes diamonds that are light yellow and brown in color. Yellow and brown diamonds that fall out of the D through Z color range, as well as diamonds of other colors, such as blue, pink or green, are categorized by GIA as colored diamonds or, as many people in the jewelry trade refer to them, “Fancy Colors” [5].

Fluorescence is a diamond’s reaction to ultraviolet (UV) light. Some diamonds glow in different colors under UV light, and the general rule is to avoid them. If a diamond is put under UV light and it glows strong blue, the diamond may look dull in the sunlight. Diamonds with strong fluorescence may worth up to 20 percent less than diamonds that do not fluoresce.

4 C's of Diamonds - Cut

When a round brilliant cut diamond has been cut to precision, it means that it has been cut to mathematically correct proportions. This allows all the light entering from any direction to be totally reflected through the top and dispersed into a gorgeous display of color. Even until recent years little importance was attached to the quality of the cut. Before that time, grading was restricted solely to color and clarity. Until the beginning of 20th century, the forms of diamond cuts developed through trial and error as the optimal brilliance effect was pursued. Only since 1910 have calculations been employed which consider the optical and physical properties of diamond - such as hardness, light refraction and dispersion, in order to achieve maximum brilliance through correct proportions and symmetry. This style of cut has probably experienced the longest and most intensive history of development; it began
as long ago as the first century B.C. and only in the 20th century did it mature in the form of a round brilliant cut. Uncut diamonds hide the unique optical properties of the cut stones. Rough diamonds have a yellow, brown, or grey non-transparent skin which covers them. Only cutting can transform the unattractive 'pebble' into that crystal clear stone which, in clarity, luster and play of color surpasses all other precious stones. Most of the beauty of a cut diamond is in its amazing optical properties, particularly in the way it bends light, and its play of color [5]. The round brilliant displays these properties in the cut state where all of the factors blend in optical harmony with one another to create the highest degree of brilliance. Color and Clarity are rarity factors given to mankind by nature. As the cut reveals these qualities, it also serves as a beautifying factor that is influenced by man's skill alone.

Judgment of cut is based on one hand, on the impression gained at first sight, in which beauty and brilliance are judged purely on personal standards. Thereafter, attention must be directed to the proportions of the cut stone. Here, facet angles and proportions must be tested for accuracy. The grading of the quality of the cut is therefore always made up of two components: a subjective opinion of the brilliance effect, and an objective judgment determined by checking the craftsmanship and measuring the proportions. In contrast, to color and clarity grading, where a natural degree of rarity exists, in cut grading it is the manual skill of the stone cutter which is judged, because it has a direct influence on how beautiful the stone is.

Figure 1.17 shows popular diamond cuts and figure 1.18 shows other diamond cuts.

<table>
<thead>
<tr>
<th>Emerald Cut</th>
<th>Heart Cut</th>
<th>Marquise Cut</th>
<th>Oval Cut</th>
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<tbody>
<tr>
<td>Pear Cut</td>
<td>Princes Cut</td>
<td>Radiant Cut</td>
<td>Round Brilliant Cut</td>
</tr>
</tbody>
</table>

Figures 1.17 Popular Diamond cuts

The following are the factors which contribute to the proportions of a diamond.
- girdle diameter
- table diameter
- total depth
- crown height
- thickness of the girdle
- pavilion depth
- angle of the crown facets to plane of the girdle
- angle of the pavilion facets to plane of the girdle.

<table>
<thead>
<tr>
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<th>Kite Cut</th>
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<table>
<thead>
<tr>
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<th>Antique Rectangular Brilliant Cut</th>
<th>Square Emerald Cut</th>
<th>Round Brilliant Cut</th>
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<th>Shield Cut</th>
<th>Half-Moon Cut</th>
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<table>
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<th>Keystone Cut</th>
<th>Briolette</th>
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<table>
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<tr>
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</tbody>
</table>

Figure 1.18 Other Diamond cuts
Figure 1.19 shows the components of a diamond.

![Diagram of a diamond with labeled components: Girdle diameter, Table size, Crown, Girdle, Pavilion, Culet.]

**Figure 1.19 Components of a diamond**

Figure 1.20(a) shows light ray passing through a cut diamond and figure 1.20(b) shows light rays passing through a cut diamond of different proportions.

![Images of light rays passing through diamonds of different proportions.]

**Figure 1.20(a) Light ray passing through a cut diamond.**  **Figure 1.20(b) Light ray passing through a cut diamond of different proportions.**

The more the cutter deviates from the mathematically correct proportions, the more the brilliance is affected, and the lower is the quality of the cut. However, a very slight departure from precise standards does not enable any loss of brilliance to be seen even by the specialist. It is therefore normal practice not to apply exclusively one value, but to extend this value upwards and downwards within narrow tolerances. Only when a "Brilliant Cut" varies beyond these limits of tolerance can it
no longer be graded "excellent" but only either very good, good, fair or poor. In the modern Brilliant Cut the requirements for maximum light emission, through the table and for the greatest possible play of color on the upper crown faces, are fulfilled by a mathematical blending of the proportions.

Maximum Brilliance

It is the inter-play of luster, light refraction, total reflection, color, dispersion and scintillation. All this is the result of the practical experience and craftsmanship of the cutter, along with his applied understanding of optical law; for only when precisely calculated planes and angles are used in the brilliant cut does the stone attain its' greatest possible beauty.

External Brilliance

It is the luster, produced by the reflection of light on the surface of the facets.

Internal Brilliance

It is the refraction of total reflection of light on the pavilion facets.

Dispersive Brilliance

Splitting and scattering of light into its spectral colors.

Scintillation Brilliance

The sparkle of the stone when moved, caused by light reflections of the light source. It is the term used for the changing colors, the radiance and sparkle of the rays when the stone is moved or when the light source changes.

Total Depth

The ratio of the crown to the pavilion, and the thickness of the girdle, are the most important considerations when judging total height. Checking the correct relationship of these proportions is far more important than measuring the total depth alone.

The Table

The smaller the table, the more play of color will come through the sloping crown facets. The quantity of light reflection generated depends on the number, size and symmetrical arrangements of the facets, as well as on the quality of the polish.

Crown Height

Because of the steeply rising prices of rough diamonds, there has been a tendency over the last few years to save weight when cutting rough. This practice
has led to round brilliants with a very shallow crown and the resultant larger table. These shallow brilliants look larger than a precision cut stone of equal weight, but the dispersion based on the color separation is diminished because of the smaller crown facets. In a brilliant cut with a shallow crown and large table, the major part of the light reflected on the pavilion facets passes through the table without being scattered.

Girdle thickness

The girdle is the dividing line between crown and pavilion. Its function is to protect the edge of the stone from damage and fracture. The girdle should be very thin, so that it is just visible to the unaided eye as a light line. A thick girdle can adversely affect the color of a cut diamond, and also diminish the light yield and therefore, reduce the brilliance (light rays in the region of the girdle width are refracted into the air and not totally reflected). This applies to girdles left in a natural state, as well as to polished or faceted girdles, which only reinforce the perfection of a well made stone if it is also thin and even. Completely or partially knife-edge girdles are dangerous, as they easily fracture during setting of the stone and can thus produce nicks and cleavage cracks.

Pavilion Depth

In order to understand the important function of the pavilion facets, it must be realized that the light falling from above into a brilliant can only be reflected back by total internal reflection on the pavilion facets, if and only if the angle between the pavilion facets and the girdle corresponds to the mathematically correct angle [5].

C's of the Diamond - Cut / Ideal Cut Diamond

Cut is the least understood factor in diamond grading. In gem quality diamonds, Cut has more to do with beauty than any single characteristic of the 4 C’s. Cut has a lot to do with value and price, too. One may choose to compromise on color, clarity or size, but to ensure having the most brilliant diamond possible; never can a compromise be made on cut. An Ideal Cut is simply a diamond cut to ideal proportions [5]. In the early 1900s, mathematician Marcel Tolkowsky published the results of his work (Diamond Design, London, 1919) which became the basis for the model known today as the "Ideal cut". Although present tastes call for slightly larger tables than the 53% of the girdle diameter that was worked out by Tolkowsky, for almost seven decades this basic formula remains the standard in the diamond world. Ideal cut dictates that every facet be placed at exact angles and proportions that create an ideal balance between maximum brilliance and dispersion or "fire". To gain this
optimum reflection and refraction of light, the cutter must be willing to sacrifice expensive material, losing valuable carat weight to yield a smaller diamond of superior beauty.

Most diamonds are cut for weight and therefore precise angles and percentages are routinely ignored. Diamond cutters usually decide to sacrifice some beauty to make a heavier diamond and as a result less than 1% of diamonds are cut to ideal proportions. The larger diamond with average cutting is produced in less time, at lower cost and of course, is not as beautiful as it could be. Ideal cut diamonds are not for everyone and because they are more costly they appeal to that unique individual who appreciates and demands excellence.

The ideal cut diamond has remained the undisputed "king of cut" in the diamond world for decades. It has long been heralded for its ideal balance of maximum reflection and dispersion. However, in the last twenty years or so, some ideal manufacturers began to drift away from the strict proportions prescribed by Marcel Tolkowsky. The reasons for this evolution revolve around yield trying to get a diamond with more carat (ct) weight, big price jumps between size categories i.e., .69-.70 ct., .89-.90 ct., .99-1.00 ct., etc. and the spiraling cost of rough diamonds. Strict proportions limits were compromised and table size percentages grew to 57% maximum from the 53% of Tolkowsky [5]. Perfect polish and symmetry became less important.

Economics takes precedence over perfection

As cutters deviated from the strict Tolkowsky specifications their diamonds lost some of their potential for perfection. Ideal cut became what it is today... an ideal range of specifications known as the American Brilliant Cut. Major American manufacturers of ideal cut diamonds began to manufacture in lower wages countries in search of low production costs. These diamonds once fashioned one by one, with the utmost of care, were mass produced in large factories. Stones cut on automated equipment often receive little individual attention. Their automatic machines were set to produce hundreds of diamonds a week in the ideal range. As a result, some became perfect ideal cuts with top polish and symmetry. Still others barely made the grade; their polish and symmetry only disappointingly average. Fortunately, not all cutters followed this trend and some continued to turn out superior ideal cut diamonds. They realize the beauty that comes from finishing the job. Today, ideal cut diamonds still reign far above average cut diamonds in both beauty and
The gemological world has its own unique culture. It has its own histories and discoveries, myths and wonders, language, and legendary personalities. Perhaps one of the most famous names in the gemological world, and certainly in that portion concerned with diamonds, is Marcel Tolkowsky. In the years since he outlined his idea of optimum diamond proportions in 1919, his name has been synonymous with "well-cut" diamonds [29]. Even a casual glance through internet diamond retail sites reveals numerous (sometimes reverential) mentions of his name.

Marcel Tolkowsky was born in Antwerp in 1899, on the eve of the twentieth century. He died in New York 92 years later, in February 1991, almost seeing that century to a close. Marcel Tolkowsky was born into a leading family of diamond cutters, cleavers, and dealers, and was related to another important family in the world of diamonds. Initially educated at the German School in Antwerp, Marcel continued at the Lycée Français and the University of London (where he studied for a D.Sc. in engineering). In 1919, he published a book that would forever engrave his name into the annals of diamond history. Although ‘Diamond Design’ was small in size (104 pages), it had a large effect on the world of diamonds.

Tolkowsky, in ‘Diamond Design’, was the first to provide a mathematical analysis of diamond cut. The book contains three parts: one on diamond history, one on the field of optics as understood at that time, and one that mathematically examines different geometric shapes in an effort to better understand round brilliant diamond proportions. Tolkowsky provided mathematical support for a new style of cutting round brilliant diamonds that was becoming increasingly popular in his time (especially in America). Different versions of this style would become known as the "Tolkowsky Cut," the "Modern Brilliant Cut," and the "American Ideal Cut." Although Tolkowsky wasn't the first to suggest diamond proportions in these ranges, he was the first to publish a mathematical foundation that supported these proportions. Tolkowsky determined that an "optimum" pavilion angle for a "balance" of dispersed light (i.e., fire) and light strength (i.e., brilliance) is 40.75 degrees [29]. This angle mostly applies to light rays that enter the diamond from angles close to perpendicular to the table. Tolkowsky then considers the bezel angles (which would translate into crown angles) that are needed to "fix" and ensure dispersion of those light rays that enter the diamond from oblique angles (i.e., those angles that are more...
parallel to the table). It is in this step that Tolkowsky determines that a crown angle of 34.5 degrees and a table size of 53% are optimal. Tolkowsky’s cut proportions for round brilliant cut diamond are shown in figure 1.21.

![Figure 1.21 Tolkowsky’s cut proportions for round brilliant cut diamond [30].](image)

The Depth (Or Height) Of the Diamond

Tolkowsky’s recommended cut height for a Round Brilliant is 59.3% that of the diameter of the diamond, which breaks down to about 43% for the pavilion, and 16% for the height of the crown. This 59% is probably the most crucial dimension of the stone. When buying a diamond, it is essential to add 1-2% for a decent girdle. It is possible to see diamonds that are too shallow (the height is significantly smaller than 59%) or too chunky (significantly over 59%). Stones which deviate too much from this value should not be bought. In practical terms it is essential to find a diamond at approximately 60% depth and 60% in table percentage as a good rule of thumb [30].

The Table of the Diamond

Probably the most noticeable proportion on a Brilliant Cut diamond is the size of the table. Tolkowsky found the table to be ideal at 53% of the diameter of the stone. The appraising guidelines penalize diamonds with tables above 64% severely. Table percentage should be in the upper fifties or lower sixties.

It can be seen from the figure 1.22, a diamond that is cut either too shallow or too deep allows light to pass out through the bottom of the stone. A
properly cut stone will reflect the vast majority of the light that enters the stone through the top of the stone back to the eye of the viewer.

**LIGHT PATHS IN A ROUND BRILLIANT DIAMOND**

---

**IDEAL CUT**  
**DEEP CUT**  
**SHALLOW CUT**

Figure 1.22 The effects of depth on diamond beauty

The Girdle

The girdle is the widest part of the stone. Traditionally it has been left in rough, so it looks like a ground glass. However, in the past few years a lot of stones have faceted girdles, 32 facets all the way around. A polished girdle might also be seen.

The girdle should not be too thick or too thin. The more uniform around it is the better. On most certifications, the girdle will be described as 'thin, 'medium', etc., or as within a range, such as 'very thin to thin'. Diamonds having a sharp, knife-edge girdle, may more easily become chipped during mounting or wearing.

The Diamond's Crown

The table is the upper flat facet of a stone. It is an octagon, each edge of which has a triangular facet adjacent to it, called a star facet. Two sides of neighboring star facets make two edges of a four-sided facet called a kite facet. One vertex of a kite facet is also a vertex of the table, and the opposite vertex is on the girdle (the edge of a cut gem). The triangular area of the crown between the bottom edge of one kite facet, the bottom edge of the neighboring kite facet, and the girdle, is divided radially into two entiomeric triangular facets called upper girdle facets. So, there is one table, eight star facets, eight kite facets, and 16 entiomeric upper girdle facets, for the total of 33 facets [30]. The facets are shown in figure 1.23.
It is important that the edges of the facets come to nice, pointed vertices (a vertex is the point where two sides of an angle intersect). Having extra tiny facets is referred to as an "extra facet", and detracts somewhat. A smaller point to consider when judging the crown is the location of the vertex where a star facet, two kite facets, and two upper girdle facets come together. This is the only vertex on the crown which is neither on the table nor on the girdle. It should be located halfway between the table edge and the girdle.

Basically, ideal cut diamonds are diamonds of a superior make that are cut to display optimum brilliance and dispersion [31]. AGS (American Gem Society), EGL (European Gemological Laboratory), GIA (Gemological Institute of America), Hearts and Arrows, European Ideal, Tolkowsky, zero cut, triple zero cut, are many differing standards and ranges. "Ideal" is a range and not specific. For a diamond to be considered ideal cut all the components (facets, table, crown, pavilion, etc.) must be cut to specific tolerances (angles and percentages). If not, brilliance and dispersion will suffer. Consider that all of these ranges when combined will not necessarily comprise an ideal cut. For instance the depth of the diamond (table to culet) should not exceed 59.3% of the diamonds diameter. Also, if the crown or pavilion angles are borderline it may wind up with a diamond that has too shallow or too deep a cut to be considered ideal, that is, 33.7 degree crown angle and a 40 degree pavilion angle would be too shallow [31]. If a round brilliant diamond is cut too deep (nailhead) or too shallow (fisheye) light leaks out of the pavilion and does not return
to the observer's eye. In diamonds with too steep a crown angle (>38deg.), exiting light is directed out to the side where it isn't visible, or it can be reflected back into the stone. In diamonds with large tables, if the crown angle is too shallow (<30deg.) there is little visible dispersion of light. Figure 1.24 and figure 1.25 show the typical proportion ranges for ideal cut diamonds.

Figure 1.24 Typical proportion ranges (not specific proportions) for Ideal cut Diamonds [31]

Figure 1.25 Range of ideal cut proportions (Deviation from Tolkowsky specifications)

In general, the awe-striking beauty of a cut diamond emanates from its inherent physical and optical properties in combination with a cutter's ability to maximize the display of these properties. It is the precision, care and artistry, which the cutter brings to the stone that releases the diamond's full potential. In purchasing a diamond it is necessary to consider two elements of cutting, which are of prime
importance - proportion and finish (which is further sub-divided into two categories, polish and symmetry). The modern round brilliant cut diamond is the most popular shape sold and it produces the best light return, in the form of brilliance, dispersion and scintillation, to the eye. What goes into evaluating the cut proportion and finish of a standard round brilliant (SRB) diamond can be easily understood by considering figure 1.26 which shows each element of the finished product. Down the left-hand side are listed the major structural features of the diamond, and down the right-hand side the different facet names.

![Figure 1.26 Standard round brilliant cut diamond.](image)

There are a total of 58 facets, called the table (1) and culet (1), bezel (8), star (8), upper girdle (16), lower girdle (16) and pavilion (8) facets. Often there is no culet facet and the stone is pointed on the bottom, leaving a total of 57 facets. Also, in higher quality goods the girdle is frequently faceted, but these facets are not counted in the total.

‘Finish’, which includes polish and symmetry, is also an important contributor to a diamond's beauty.

‘Polish’ features largely describe the condition of the surface of the stone, and include abrasions of the facet junctions and the culet, rough and bearded girdles, nicks and pits, and scratches and polishing marks if they do not affect the clarity grade. It is a grade given to the external finish of a stone [32]. The polish grades from poor to excellent. Good polish is crucial for maximum brilliance of a diamond, but it takes a trained eye to distinguish between polish grades. Extra facets to remove a part of the rough are common, as well as grainy lines that are visible only under a loupe or microscope.
'Symmetry' characteristics include many features of poor and/or careless workmanship such as an off-center table or culet, a table not a regular octagon shape, an out-of-round or wavy girdle, non-parallel girdle and table, facets which don't meet or point properly or are misaligned between the crown and pavilion, and naturals and extra facets which are not graded under clarity.

'Proportion' - The full realization of the potential of a diamond's brilliance, dispersion and scintillation and getting the proper balance between these three elements is achieved mainly through proper cut proportions. The important proportions are listed below.
1. Table size
2. Crown height and angle (angle of the bezel facets with the girdle)
3. Pavilion depth and angle (angle of the pavilion facets with the girdle)
4. Girdle thickness
5. Culet size

'Make' is a trade term used to describe how closely the proportions of a brilliant cut diamond are to an "ideal". For stones approaching these proportions a diamond is said to be of good or fine make, and for those with problems of proportion are referred to as being of fair or poor make. While there are different sets of criteria (the definition of Ideal can vary.) for what constitutes an Ideal cut in a round brilliant diamond, there are presently none for the other fancy shaped cuts (oval, marquise, emerald, radiant, princess, heart, pear).

The Effect of cut quality on price and the Fifth C 'Cost'

The Effect of cut quality on price is another important aspect. Cut quality commands a premium for two reasons. First, paying for a highly skilled diamond cutter's time, and it can take many hours to get all the proportions and angles to fall within the Ideal ranges. Second, more of the diamond is lost in the cutting process, because the goal is not to cut the heaviest diamond, but the best performing diamond.

Cost refers to the problem that one must determine what one can afford. Many gem buyers have been frustrated because they know what the best color, clarity, size, and cutting characteristics are and then demand them [30]. The obvious conclusion is made that they are being overcharged when the quality they demand is actually presented. Sadly, they often gravitate to a dealer that will overstate the quality of a lower quality gem at the "right" price.
1.1.2 The Imposters

An "Imposter" is any gem that claims to be as good or better than, just like, as hard, more beautiful than, but cheaper than a diamond. The "Imposters" come in two groups, the simulants and the synthetics [33]. A simulant is something that looks similar to a diamond but does not have the same properties (weight, specific gravity, refractive index, hardness, etc.). A "Simulant" or "Imitation" is a look alike to the real gemstone. Chemical composition and physical properties are not the same - only looks alike. This is often the case where colored glass is cut and looks like ruby, sapphire or emerald. A typical example is Cubic Zirconia - total man made, no natural counterpart, but when cut might look like a natural stone. A synthetic is a man-made diamond that has all the properties of a natural diamond (weight, specific gravity, refractive index, hardness, etc.) A "Synthetic" gemstone, also called Lab Created, is created in controlled laboratory conditions and reflects identical chemical composition and physical properties to that of the natural gemstone [34]. Various methods are used to create synthetic gemstones, some cheap and some very expensive. Sometimes a Lab Created gemstone can even cost more than the natural counterpart! Quality and color can vary tremendously and this also affects the prices and beauty.

A "Fake" is any item being presented as something else. It can be a piece of glass said to be emerald, garnet said to be ruby, moissanite presented as diamond. A synthetic ruby is not a fake, but synthetic or man made as it is still exactly the same composition as the natural ruby. If someone sells a natural chrome tourmaline as emerald - it is a fake emerald!

The terms Natural, Synthetic, Simulant, and man-made [35] have been designed by the Gemological Institute of America for the classification of precious stones. They are specific to the GIA and may not necessarily be used in any other field.

Synthetic: A man-made mineral that has the same chemical and optical properties as the natural mineral.

Simulant: A material that is meant to act as a gem replacement, not necessarily man-made nor has the same chemistry or optical properties. An example is Cubic Zirconia used in place of Diamond.

Man-made: A material that is human manufactured, but is not a replacement for another stone.
Cubic Zirconium Oxide - Cubic Zirconium commonly called Cubic Zirconia (CZ) is a simulant for diamond. CZ has a greater fire than diamond and is almost as hard, 8.5 on the Mohs scale.

Cubic Zirconia Information and Jewelry

Cubic Zirconia, contrary to public belief, can be found in the natural world but is extremely rare. Cubic Zirconia was first discovered in 1937 by two German mineralogists but in very minute quantities [36]. The two mineralogists thought so little of their discovery that they did not even give it a name; which is why it is still known by its scientific name, cubic Zirconia [37]. Then in the early 1970's Russian scientists began to grow Cubic Zirconia under laboratory conditions, not for jewelry making but for industrial use and space technology. In the 1980's mass production of Cubic Zirconia started. Since then, Cubic Zirconia has become extremely popular with jewelry designers and is widely available. Because of its similarities to mineral gemstones it wasn't long before attention was focused on the jewelry possibilities of this new man made material.

American Diamond Jewelry in India

No longer are diamonds the exclusive preserve of the super-rich. American diamond jewelry—with its inexpensive price tag and expensive looks—has made a flashy debut in the jewelry market. Jewelry and woman go together and when the jewel is made from stones like diamonds refuse a chance of wearing it. In today's fast paced world, however, real jewelry can be quite expensive, and not exactly a security man’s delight. Yet a woman can satisfy her desires to adorn herself with equally sparkling diamonds that do not necessarily have to be the real thing. The success of Cubic Zirconia, or American diamonds as it is nicknamed by the trade because of its origin of development, has made it very easy for the modern Indian woman to dazzle without getting unduly worried about the price or the risk factors [38]. To replace the real diamond several alternatives have been tried: Lead crystals, highly compressed graphite and Carborundum, for example. But the Cubic Zirconia produced initially in the Soviet Union received the most approval. Later in the 70s, the General Electric Company of USA perfected by discarding as many impurities as possible to bring it closest to the original gem. The Diamond and Gem Development Corporation (DGDC) factory manufactured the Cubic Zirconia by a process called Skull Melting. So far the raw material for its manufacture has to be imported since the process has not yet been perfected in the country. The price of the Cubic Zirconia is
only a few thousand rupees per kilo and that is what makes it so attractive in comparison with the real diamond. Yet the smaller the stone the higher the price while for a real diamond it is the other way round.

The Cubic Zirconia after cutting and polishing is re-exported to the west. As with real diamonds, it is also based on the rough. So if the rough is inferior then the end product will be of the same level. But often the fake is more brilliant than the real diamond and the end result at times is so good that it is hard to tell the difference between a Cubic Zirconia and a real diamond. The 4Cs apply to Cubic Zirconia too. They are the cut, color, clarity and carat. The carat is different since the specific gravity is higher as it is heavier. Besides, the Zirconia is not as hard as a real diamond and so cannot be used for industrial purposes. As an item of investment the Zirconia has no resale value. It is for purely aesthetic purposes and only when set in jewelry can it be sold. Price wise, jewelry in Zirconia is very competitive, where a good real one carat diamond would cost around Rs.75,000 a similar one in a Cubic Zirconia would only be a few hundred rupees. Therefore earrings could sell for Rs.300/- to 400/-, bracelets, bangles for Rs.1200/- to 5500/- pendants Rs.300 to 1200/- and cuff links, tie pins, kurta buttons for Rs.600/-.

The boom in the sale of American diamond jewelry in the local market encouraged the DGDC to manufacture and sell synthetic gemstone in 1989. New units were added every year. The sale of this jewelry is year round with an increasing during the festive months. Tourists are attracted to American diamond jewelry made in India but it hasn’t become a foreign exchange earner. As a jewelry item it is antidowry and a social equalizer. Investing in real diamonds which are really dead assets with fluctuating prices, is now becoming a thing of the past. A Zirconia’s rate doesn’t fluctuate and loosens up the parallel economy. Designing in American diamond jewelry has reached a traditional as well as an international look. The stones are normally set in silver plated with gold. In fact, the Cubic Zirconia has been so indistinguishable from a real diamond that it has at times even confused jewelers. The only fool-proof way to tell the difference is by the thermal conductivity method which is used at international airports and customs sections. As far as the durability of this diamond is concerned it is comparable to the real thing. The normal standard precautions applicable to a real diamond are followed. The Zirconia is more brilliant than the real diamond and in addition to other colors has flashes of red and yellow. The stone does not blacken nor does it wear away.
The customer profile comprises the woman who does not want an obvious fake item but is able to present a prestigious as well as fashionable image. The working woman who wants to flash a subtle diamond and express her tastes in the right direction opts for a Zirconia jewelry piece. With this type of jewelry one can buy a good piece of jewelry, which is cheap. Cubic Zirconia, often abbreviated to CZ, is a synthetic stone used as a diamond simulant [39]. Cubic Zirconia is an oxide of the metallic element - Zirconium (ZrO2). In colored forms of Cubic Zirconia oxides of other metals such as copper, iron, nickel and many others are added in varying degrees. Cubic Zirconia is mostly an amalgamation of approximately 87% zirconium oxide and 13% yttrium oxide although different "recipes" are used all over the world. The quality of the stone is usually influenced by the high heat induced formation process and by the type and quantity of the stabilizing material that's needed to "bond" the Cubic Zirconia atoms after cooling. Some Cubic Zirconia can suffer optical degradation in that the stone either discolors or clouds over time, whereas other forms will remain colorless and transparent.

Cubic Zirconia is the best diamond simulant currently available; its appearance is almost identical to diamonds. Furthermore, the chemical and physical properties of Cubic Zirconia are very similar to diamonds. Cubic Zirconia has slightly less brilliance (sparkle) than diamonds, but much greater fire (flashes of rainbow colors). Even trained gemologists are often unable to distinguish between diamonds and cubic Zirconia unless through a jeweler's loupe. Using the naked eye, it is virtually impossible to tell the difference.

Cubic Zirconia is a relatively hard stone of excellent durability which makes it ideal for use in gold, platinum and silver jewelry. Cubic Zirconia are approximately 75% heavier than diamonds [40, 37]. This is important because some will state the carat weight in terms of Cubic Zirconia, while others quote carat weight in diamond equivalents. If carat weight is given strictly for cubic Zirconia, then a 1 carat cubic Zirconia would be smaller than a 1 carat diamond. Therefore, it is useful to know which system is being used. Today Cubic Zirconia is produced in fancy colors, such as red, green, pink, and yellow- simulating the fancy colored diamonds.

When purchasing jewelry for formal occasions, Cubic Zirconia is an excellent choice. While the cost of elaborate diamond necklaces, earrings, pendants etc... may be prohibitive, Cubic Zirconia jewelry is just as beautiful and much more affordable.
Cubic Zirconia is widely used in the Jewelry industry as a simulant because it looks very similar to diamond. Perfectly transparent and colorless it is highly lustrous [41]. It can be cut to great precision. Cubic Zirconia is hard and the cost is very low. It is also available in color. Main sources are United States, Switzerland, Thailand and China. CZ scores an impressive 8.5 on the Mohs scale but is not resistant to wear and chipping and does require care by the wearer [36]. Cubic Zirconia's best properties are its light (optical properties) and its relative cheap financial value. To the untrained eye, CZ looks identical to diamond and can fool plenty of so called "knowledgeable" jewelers. It can also fool unsuspecting buyers who might think they are buying diamond!

Diamond Differences

The biggest giveaway is weight. A 1 carat diamond weighs 1 carat. A comparable sized (in volume) CZ weighs 1.75 carats [36]. A Cubic Zirconia can be scratched by diamond, topaz, ruby or sapphire whereas a diamond can only be scratched by another diamond. The optical differences make comparisons between these two stones very interesting. A diamond displays more brilliance, whereas a Cubic Zirconia has more fire. Even though a CZ has more fire, it is far more intense than a diamond's fire which shows a more color balanced "natural" fire. The difference in brilliance and fire is caused by smaller amounts of light being reflected back from the inside of a Cubic Zirconia stone.

The refractive index for diamond is 2.417. The refractive index for Cubic Zirconia is 2.17, very close to the refractive index of diamond [42]. Basically speaking Cubic Zirconia has a smaller refractive index which causes light to bend at a much shallower angle and therefore more light is lost through the stone rather than being reflected back from it. This probably accounts for some of the extra fire [36]. The other big difference to consider is that 99.9% of diamonds are imperfect in some way or another and this adds to their overall character and cannot be easily be reproduced by Cubic Zirconia. A colorless diamond is extremely rare - they usually have some kind of yellowish tint which on most occasions isn't apparent to the naked eye - a CZ on the other hand is almost perfectly transparent. Cheap CZ's are always machine cut, while a more expensive CZ will have been worked on by human hand to produce the best possible CZ gemstone.
Cubic Zirconia Properties

Material: Cubic Zirconia (ZrO₂). This single crystal optically clear form of ZrO₂ has a relatively low fracture toughness and strength, but very high thermal shock resistance.

Today's technology makes it very difficult to distinguish a real diamond from a Cubic Zirconia. It usually takes a jewelers magnifying glass and a lot of expertise to tell the difference. These are not simulated diamonds, they are synthetic. They are not copies. They are engineered to be man-made replicas of the natural stone [43].

The technical Information [44] is given in table 1.4.

<table>
<thead>
<tr>
<th>Chemical Composition and Name</th>
<th>ZrO₂ - Zirconium Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>8.25 to 8.5</td>
</tr>
<tr>
<td>Refractive Index</td>
<td>2.15</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>5.65 - 5.95</td>
</tr>
<tr>
<td>Crystalline System</td>
<td>Cubic</td>
</tr>
</tbody>
</table>

Table 1.4 Properties of CZ

The following tests identify Cubic Zirconia:

- Cubic Zirconia can be identified by a specific gravity test of an unmounted stone.
- Cubic Zirconia can be identified by marking ink on the table (flat top) of the stone; on cubic Zirconia ink beads up.
- When measured for heat conductivity with diamond probe, Cubic Zirconia and other imitations register red on the indicator; diamond registers green.

Properties of Cubic Zirconia can be summarized as below [45].

Cubic Zirconia...man made

Colors: all

Hardness: 8.5

Specific gravity: 5.8 ± .2

Refractive index: 2.15 ± .03

Occurrence: man made

Crystal or stone size: up to 2" usual 1" or less

Comments: usually orange or yellow fluorescence under UV.
1.2 The Need for Distinguishing Original Diamonds from Fake Diamonds

The price or cost of the original diamonds is many times greater compared to that of the CZ. When the customers have to pay a huge sum for a diamond of a very small size, it is necessary that he is aware of the properties of both the original as well as the fake diamonds. This work is limited with only one variety of diamond stimulant which is the most commonly used, namely Cubic Zirconia. The price fixed for a gemstone by the seller depends on the trust or the confidence that the customer has on the seller. Gem News International contributor Dr. Henry Hänni reports that, two pieces of diamond rough (8.71 and 23.57 ct) were submitted to the laboratory of the SSEF Swiss Gemological Institute for identification. The original seller in Brazil represented them as diamonds, and “confirmed” the identification with a diamond probe. Both looked like broken crystal fragments, and did not initially appear to be imitations. The 23.57 ct stone, which had an S.G. of 3.56 (measured hydrostatically), was identified as topaz. The 8.71 ct sample, which had an S.G. of 5.89, was found to be Cubic Zirconia [46]. When exposed to long-wave UV radiation, the 8.71 ct sample showed one spot that fluoresced blue. Microscopic examination revealed that the fluorescent area corresponded to a $2 \times 1.5$ mm colorless fragment that was attached to the surface. Testing with a diamond probe indicated that this fragment was diamond. Further examination of the 23.57 ct sample revealed that it also had a diamond fragment attached to its surface. In this case, the $2 \times 2$ mm fragment did not show any fluorescence. On both samples, the pieces of diamond were glued into notches where the dealer could easily place the diamond probe, making them particularly deceptive imitations.

Some less reliable methods for identifying original diamonds from Cubic Zirconia [33] are given below.

1. The old “If it will scratch glass it has to be a diamond.” It is true that diamonds do scratch glass but so do a lot of the other fakes on the market.

2. The transparency test. If the diamond in question is flipped upside down and placed over some newsprint and can clearly read through the stone, it’s not a diamond. (The problem with this test is some diamonds are cut shallow and can be read through.)

3. The fog test. Put the rock in front of the mouth and fog it like trying to fog a mirror. If it stays fogged for 2-4 seconds, it’s a fake. A real diamond disperses the heat instantaneously so by the time it is looked at, it has already cleared up. (A down
fall to this test is oil and dirt on the stone can effect its reliability and the test is not accurate at all on doublets where the top of the stone is diamond and the bottom is Cubic Zirconia epoxied together.)

4. The weight test. The most popular of diamond simulants (fake) is a cubic Zirconia. C.Z.'s weigh approximately 55% more than diamonds for the same shape and dimension.

5. The U.V. test. A high percentage of diamonds fluorescence blue when put under an ultra violet light (black light). Since 99% of all fakes don’t, a positive identification of medium to strong blue would indicate a diamond. The bad news is if this method proves it to be a diamond, it also proves the diamond is worth less. Diamonds with blue fluorescence are as much as 20% less valuable. Lack of blue fluorescence doesn’t mean it’s a fake; it could just be a better quality diamond.

6. Under the loupe test. With some sort of magnifying lens, there are some things that can be looked for on the stone that might give away its identity:

A. By looking at the rock from the top and see how well the facets (cuts on top of the diamond) are joined. They should be sharp not rolled.

B. By looking at the girdle and seeing if it is faceted or frosty (a clear sign it’s a diamond) or waxy and slick (an indication it’s a fake).

C. While looking at the stone under magnification, look into the stone to see if it is possible to detect any flaws (carbon, pinpoints, small cracks). These are typically clear indications it’s the real thing since it’s very hard to put inclusions in a fake.

The commonly used Gem testing instruments are shown in figures 1.27(a) and 1.27(b).

![Figure 1.27 (a) Microscope](image)

![Figure 1.27 (b) 10X Hand Loupe](image)

The most common method used by the diamond traders for assaying the quality of the diamond is the use of a 10X loupe, a lens that magnifies the object
ten times than its original size. The clarity of a diamond has to be examined under normalized light. This lens helps to study the cutting and inclusions in the gem. In the place of 10X loupe, 20X or even 30X loupe may be used. Microscope that facilitates zoom-in as well as zoom-out for the purpose of studying the inclusions, and Refractometer to find out the index of refraction are other testing instruments used in the scientific method of assaying the diamond quality. The proposed research work aims at making it possible for the customer or owner of the diamond to test or analyze his diamond by himself sitting at home, using his own computer. The present work is concerned with the analysis of only colorless, unmounted, round brilliant cut original diamonds and Cubic Zirconia.

1.3 The State of the Art

Computer Modeling

Computers allow the detailed modeling of diamonds and their environment by calculating the complex interactions between variables that occur when light interacts with diamond. However, a computer can accomplish this only after the essential components-such as diamond proportions and the laws of optics-have been programmed into its software. The first step in this process is to separate components into larger groups and then define the specific attributes of each component in that group. Diamond appearance relies primarily on the interaction of three main groups: the diamond, the environment (especially lighting), and the observer [48]. In simplistic terms the three things needed to appreciate the sparkle of a diamond are an observer, a diamond and a light source [49]. In GIA's research on diamond appearance, the computer model consists of a virtual diamond, a virtual environment (that includes factors such as a virtual light source), and a virtual observer. These three components define the computer model (that is, all three components must be accounted for in some way for the model to be complete). However, researchers are free to specify and adjust any or all of the attributes of the model components in their attempt to re-create certain real-world relationships. Each adjustment of the model's components leads to a different kind of numerical result, or metric, although each new metric is still part of the same, original model.

The process of developing and testing a computer model is often lengthy and painstaking. Each new set of relationships between the components of the model must be developed, calculated, validated through a series of verification tests, and adjusted until a statistically significant correlation is found. Researchers often
develop hundreds of metrics in their search for the one that matches the particular real-world circumstances they are trying to represent with their model. In each case, one thing is certain: When any of the components or relationships between components in the real world is changed, it is necessary to change the metric to correspond to it [49]. Each new metric, however, is still a part of the original computer model.

As diamond is a three-dimensional (height, width, and depth) object, and cut parameters play an important role in increasing or decreasing the diamond quality, a three-dimensional simulation model can suggest which cut parameters can yield maximum light return and fire. The three dimensional modeling is to generate photorealistic images of diamonds of different shapes, allowing the user to vary the cut parameters, illumination conditions and optical characteristics of the gem materials. With such models it is possible to observe ray tracing, inclusion reflections, and other optical effects that occur in diamonds. There are specialized software like “Brill”, developed by the Moscow State University researchers and the “Diamond Calculator” developed by the Gemological Institute of America.

The “Brill” software and the technique used

As diamond is a three-dimensional object, and cut parameters play an important role in increasing or decreasing the diamond quality, understanding how a three-dimensional simulation model can suggest which cut parameters can yield maximum light return and fire, became essential for the present work. For this purpose, a theoretical study was made on the specialized software “Brill” developed by the Moscow State University researchers. The technique used is a mathematical model which while maintaining the shape and pattern of the facets of a round diamond, the cut parameters are varied to find out those values providing the maximum light return and fire. This mathematical model consists of the following parts [50].

1. Illumination sources

The illumination model involves a set of up to 100 virtual sources of white light each having its own position and angular size.

2. Diamond

The diamond under study is chosen to have a standard round brilliant cut with a pointed culet and faceted girdle, with ideal symmetry and ideally polished flat faces. The computer builds up a complete 3-D parametric model
of diamond cut, the shape of which is determined by the following parameters (shown in figure 1.28).

![Diamond Parameters Diagram](image)

Figure 1.28 The Diamond Parameters [50]

a. A (Crown angle)
b. B (Pavilion angle)
c. $D_p$ (table size)
d. $q$ (lower girdle facet size)
e. $h$ (minimum girdle thickness)
f. $G_d$ (maximum girdle thickness)

The fixed parameters are: $h = 1\%$ (at the narrow part) and $q = 0.82$.

3. Ray tracing

The calculations deal with multiple ray tracing. The maximum number of the multiple reflections of a single ray in round brilliant cut is considered as 20.

4. Observer

The software models the angular size of the observer's pupil. It is taken into account that the observer's head screens some of the illumination sources. The screening of illumination sources by the observer's body is kept in mind when arranging the sources.
5. Absorption

When modeling a colorless diamond, absorption inside the crystal is neglected.

6. Coefficients for quantitative analysis of modeling results

a. The light return coefficient LR is defined as the white fraction of the incident light returned by the diamond to the observer's eye.

b. The fire coefficient F is defined as the mathematical color dispersion (a quantity characterizing the deviation of observed colors from white) of highlights visible on the surface of the diamond.

c. The Q-factor takes into account both its light return and fire. This factor is the measure of cut quality.

d. If an increase in the cut quality reduces the weight of the cut diamond, the economic efficiency of such a cutting process may appear to be far too low. This is because the price of the diamond depends on both its cut quality and weight. The commercial efficiency of the cutting process is estimated with the efficiency function: \( \text{EFF} = Q^2M \) where \( Q \) is the cut quality and \( M \) is the diamond weight.

7. Tolkowsky diamond: According to Marcel Tolkowsky, the following are the parameters of calculated diamond cut.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown angle</td>
<td>34.5°</td>
</tr>
<tr>
<td>Pavilion angle</td>
<td>40.75°</td>
</tr>
<tr>
<td>Table size</td>
<td>53 %</td>
</tr>
<tr>
<td>Girdle thickness</td>
<td>1 % (at the narrow part) 2.7 % (at the thick part)</td>
</tr>
<tr>
<td>Star length</td>
<td>0.37</td>
</tr>
<tr>
<td>Lower girdle length</td>
<td>0.82</td>
</tr>
<tr>
<td>Pointed culet</td>
<td></td>
</tr>
</tbody>
</table>

Key results of Brill software

The cut parameters vary for different diamond patterns. Some of the known results are shown in figures 1.29, 1.30 and 1.31.
Thus, three dimensional modeling is to generate photorealistic images (figures 1.32, 1.33 and 1.34) of diamonds of different shapes, allowing the user to vary the cut parameters, illumination conditions and optical characteristics of the gem materials. With such models it is possible to observe ray tracing, inclusion reflections, and other optical effects that occur in diamonds.

Limitations of Brill software

This model, even though three dimensional, it does not serve to differentiate between the original and simulants, but provides an understanding of how the general principles of light interact with the diamond and what cut parameters will result in maximum light return and fire.
The Diamond Calculator

Diamond calculator is a computer software to model polished gemstones, which enables precise calculation of the weight and determination of the cut proportions. The real (photoreal) image of a polished diamond created by the system makes it possible to determine the cut parameters that cannot be measured directly and to select the optimal combination of the parameters to obtain the best perception (luster, brilliance, fire) of the stone. Necessary cut parameters can be obtained by comparison of the real diamond to a computer image. The Diamond Calculator developed by GIA is shown in figure 1.35.
Natural diamond (colorless)

**DIAMOND grading REPORT**

**Report No.**

**Shape:** Marquise

**Weight:** 0.59 ct.

**Dimensions:** Max. 9.43 Min 4.29 x Dep. 2.70 mm

**Total Depth:** 63.0 %

**Table:** 52.6 %

**Girdle thickness:** Medium

**Culet**

**CUTTING/PROPORTIONS GRADE:**
according to GIA appraising system.

**GIA COLOR:** *H*

| D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
| Colorless | Near Colorless | Slightly tinted | Very Light Yellow | Light Yellow | |

**GIA CLARITY:** *VS1*

<table>
<thead>
<tr>
<th>F</th>
<th>IF</th>
<th>VVS1</th>
<th>VVS2</th>
<th>VS1</th>
<th>VS2</th>
<th>SI1</th>
<th>SI2</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flawless</td>
<td>Internally Flawless</td>
<td>Very very small inclusion</td>
<td>Very small inclusion</td>
<td>Small inclusion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Laboratory Director**

**Date:** March 20 2005

Figure 1.36 The Diamond Grading Report
Significance of Digital Image Processing

Computer modeling helps to generate three-dimensional view of the diamonds and photorealistic images of diamonds of different shapes, allowing the user to vary the cut parameters, illumination conditions and optical characteristics of the gem materials. With such models it is possible to observe ray tracing, inclusion reflections, and other optical effects that occur in diamonds. These models, even though three dimensional, they do not serve to differentiate between the original and simulants, but provide an understanding of how the general principles of light interact with the diamond and what cut parameters will result in maximum light return and fire.

These details may provide useful information to the scientists and researchers, but not to a purchaser or a customer of a diamond who may be a layman. Certificates stating the parameters and quality of the diamond may be available in GIA and other highly sophisticated countries or cities, but not in small cities like Salem, Tamilnadu, India. Hence, the present work aims at making even a layman to understand what ‘Diamond’ is with his own computer. This work uses ‘Digital Image Processing’ techniques.

The present work is concerned with the acquisition of the image of the diamond under specific conditions, digitizing it, and then processing the digital image using various ‘Image Enhancement’ techniques, to assay its quality and study its properties. The main intention of the research work carried out is to distinguish original diamond from one of its dominantly used diamond simulant, CZ.

1.4 Objectives of the Present Work

Precious metals like Gold, Silver and Platinum are valued by vendors available near all jewelries. They assay these metals by destructive procedures. Such appraisers for these metals are readily available in plenty in today’s market. They assay in terms of the percentage of purity and give the actual weight by physical methods, so that a layman can come to a conclusion about his bullion, both quantitatively as well as qualitatively. The most interesting fact is that these reports or results will tally with a very small or tolerable difference from one appraiser to another. This minor difference will not affect the value of the item or product significantly, and hence, the customer will be happy with his holdings. But in the case of gemstones especially like diamonds which are very precious, it is difficult to assay
the value because it requires nondestructive assaying methods. The gemstones are
assayed by the experts and the results depend upon their experience. These results
also vary from one appraiser to another. Even very minute variation may indicate a
change in the value of the diamonds. Hence, it is the need of the hour to find a method
which should be nondestructive, easily affordable, economical, reliable and universal
too. The present work is the outcome of this idea, which identifies or distinguishes
original diamonds from fake diamonds like Cubic Zirconia, as it is very important to
first find out which of the given two gemstones (one being original diamond, and the
other being CZ) is the original diamond, even before testing it for its quality.

The most important and interesting point is that the experiment used in
the present work follows an ‘open’ system. It can be done in front of the purchaser,
and can be done by the purchaser himself, even if he is a layman.

It is natural that the taste, liking, need, want and demand varies from
one person to another. No two persons match in this respect. This is applicable to the
diamond selection also. The general factors influencing the diamond purchase are
listed below.

1. Size of the stone
2. Number of stones required per carat (quantity and quality)
3. Color/Clarity of the stone
4. Shape of the stone
5. Brilliance/Sparkling/Luster
6. Fire/Chromatic flares
7. Affordability in terms of monetary condition of the purchaser/what amount the
   purchaser is ready to pay.

The current trend is the choice of light weight jewels with very small
sized diamonds mounted on them. It seems that the number of diamond purchasers is
increasing every year. A diamond necklace, ring and a bracelet all together are
available at a cost of just Rs.50,000/= (50,000 rupees) in today’s market in India.
Such a purchase is made by people who are not bothered about the quality of the
diamonds purchased, but only wish to own diamond jewels. But it is good to buy only
unmounted (loose) diamonds after testing them for their originality. Even a poorly cut
stone, that is appraised to be poorly cut with very little brilliance or sparkle or luster
may seem to be beautiful to the eyes of the purchaser, and sometimes even a diamond
appraised by some local appraiser, or by GIA (Gemological Institute of America) or
GII (Gemological Institute of India), to have ideal cut proportions may not be selected or chosen for purchase by the purchaser or customer due to his personal likings and taste for the item. Hence, the present work aims at “identifying original diamond from its most dominant simulant Cubic Zirconia”, and does not concentrate on finding out the cut proportions or quality of the diamond. The reason is that, today there is no single cut proportion that is called ‘ideal’, instead there exist only a range of ideal cut proportions.

Therefore, the objective of the present work is the identification of colorless, unmounted, round brilliant cut original diamond from Cubic Zirconia using digital image processing. It is concerned with:

1. Using digital image processing technique to find the girdle diameter of the given gemstone. The Elliptical Marquee tool in the powerful image editing software Adobe Photoshop is used for this purpose. Study of mass and size relationship is made by the use of Density, Mass and Volume related by the formula; Density is the ratio of Mass to the Volume, that is,

\[
\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}}.
\]

2. Using ‘thresholding’ and ‘histogram’ in the identification of original diamonds from Cubic Zirconia when the gemstones in hand that need to be tested seem to be of same dimensions, to the unaided or naked eye.

3. Using sharpening, edge detection, and blurring techniques in the identification of original diamonds from Cubic Zirconia when the gemstones in hand that need to be tested seem to be of same dimensions, to the unaided or naked eye.

4. Identification of the inclusions in original diamonds by examining them using two methods, method I and method II that apply a newly devised sharpness filter named D-filter (Diamond Filter).

Gem should never be bought as a gamble – the uneducated consumer will always lose. This is a basic rule of thumb. The best way to take the gamble out of buying a particular gem is to familiarize with the gem. While the average consumer can’t hope to make the same precise judgements as a qualified gemologist whose scientific training and wealth of practical experience provide a far greater database from which to operate, the consumer can learn to judge a stone as a “total personality” and learn what the critical factors are – color, clarity (also referred to in the trade as “perfection”), cut, brilliance, and weight – and how to balance them in judging the gem’s value [51].
Today, knowing the gems, being absolutely sure about what is bought and sold, is essential. Major changes in the gem world – new synthetic stones, new treatments to enhance and conceal new gems, and more stones available in every hue and tone of color – make accurate gem identification more important than ever to both buyers and sellers [52]. Years of training and experience are necessary to become a professional gemologist, but with practice and a little hands-on work, it can be found that it takes surprisingly little time before feeling more confident about what is bought and sold. The step-by-step system presented in this thesis is sure to help the buyer as well as the seller to be confident in whether original diamond or Cubic Zirconia is being bought or sold, using digital image processing techniques instead of the conventional methods like the usage of the 10X loupe.

1.5 Outline of the thesis

The contents of the various chapters in the thesis are briefly described below.

In Chapter 1, the need for Digital Image processing techniques in the identification of Original diamonds from Cubic Zirconia, the optical properties of original diamond and Cubic Zirconia, the need for distinguishing original diamonds from fake diamonds, the state of the art and the objectives of the present work are discussed. Further, the organization of the thesis material in the subsequent chapters is briefly outlined.

In the second chapter, the process of acquiring the images of original as well as Cubic Zirconia using scanners is discussed. Every diamond is scanned in three different views, namely, table view, pavilion view and Culet view. The file format used for saving the images scanned and the features used for processing the acquired diamond images are also explained.

The diamond has been examined using the following four different non-destructive methods.

1. Using digital image processing technique to find the girdle diameter of the given gemstone. The Elliptical Marquee tool in the powerful image editing software Adobe Photoshop is used for this purpose. Study of mass and size relationship is made by the use of Density, Mass and Volume related by the formula Density is the ratio of Mass to the Volume, that is,

\[
\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}}.
\]
The methods are explained in Chapter 3. Test results are also presented and discussed.

2. Image thresholding is a very powerful tool and it enjoys a central position in applications of image segmentation. The key and most difficult step in most image analysis procedures is the thresholding or segmentation step used to separate the image into features and background. The result of the thresholding operation is a binary image, i.e. all pixels can have only two values 0 or 1 (1 bit per pixel). Usually, pixels below the threshold are labeled 0 and pixels above the threshold 1. Selection of threshold value depends on the application, and the threshold value is fixed to be 128 in the present study. For the thresholded image, the histogram is found, and it is clearly understood that the number of edge pixels (level zero pixels) are significantly high in the case of original diamond when compared to Cubic Zirconia that seems to be of same dimensions as that of original diamond, to the unaided or naked eye. This method is explained in detail in Chapter 4.

3. The variations of image features, usually brightness, give rise to edges. An edge is the boundary between two regions with relatively distinct gray-level properties. Sharpen Edges doesn’t affect the whole image, but sees and enhances the contrast at whatever it perceives to be an edge. The Find Edges filter identifies the areas of the image with significant transitions and emphasizes the edges. The Smart Blur Filter blurs everything in the image, or selection, except the edges. Accented Edges accentuates the edges of an image. While applying each filter, the options selected have been detailed in Chapter 2. The result of processing the diamond image is a binary image. This resulting image is inverted, and its histogram is studied. A histogram illustrates how pixels in an image are distributed by graphing the number of pixels at each color intensity level. The identification of original diamond from Cubic Zirconia can be done by viewing the difference in the number of edge pixels (zero level pixels) in them after applying the sharpening, edge detection and blurring techniques as explained in Chapter 5. It is clear that the number of edge pixels (level zero pixels) are significantly high in the case of original diamond when compared to Cubic Zirconia that seems to be of same dimensions as that of original diamond, to the unaided or naked eye.
4. Chapter 6 describes the methods for examining the diamond under study for the presence of inclusions. A newly devised sharpness filter, named D-Filter (Diamond-Filter), and its importance are also described in this chapter.

Four gemstones, three gemstones seeming to be of same size and dimensions to the human eye (two original diamonds and one Cubic Zirconia), and the fourth stone of large size (one Cubic Zirconia), have been used in the present study. All these four gemstones initially assumed to be original diamonds are tested using the methods described in the Chapters 3, 4 and 5. The test results and discussions are presented in the respective chapters. Another gemstone (original diamond) with inclusions has been taken and tested for the presence of inclusions using the methods discussed in Chapter 6, and the test results are also stated.

The significance and drawbacks prevailing in the certification process and the highlights of the thesis are briefly reviewed in chapter 7. Suggestions for future research are indicated in this last chapter.