Lasers are everywhere in modern technology. Yet initially they were just a laboratory curiosity, "a solution in search of a problem." A laser (an acronym for Light Amplification by the Stimulated Emission of Radiation) was first built in 1960 by the American Theodore Maiman, mostly to prove that it could be done. He used a rod of ruby, which sounds expensive and exotic, but today lasers can use a wide range of solids, liquids, and gases as the "medium" to generate their unique radiation.

The Light Fantastic

To understand how a laser does what it does, we need to review how atoms deal with light and other radiation. Energy in atoms is stored a bit like you might store boxes, in a series of shelves, one above the other. If one shelf gave way, a box could drop without any help to a lower shelf, but lifting a box to a higher shelf takes some effort.

In atoms and molecules, the shelves are called energy levels and what they hold are not boxes but electrons. When an atom or molecule absorbs energy, say from a passing light wave, electrons are hoisted up to higher levels, and when the light wave has gone, the electrons can fall back down again, giving out exactly the same amount of energy they took in. Of course, all the atoms or molecules of the one chemical have the same arrangement of shelves, with the spacing between the shelves precisely determined.

Below: The Conservatory building in Kiev, Ukraine, was transformed by the "Sculptures by Light" hologram show. Lasers provide the coherent light source that give holograms their 3D effect.

Coherent Light

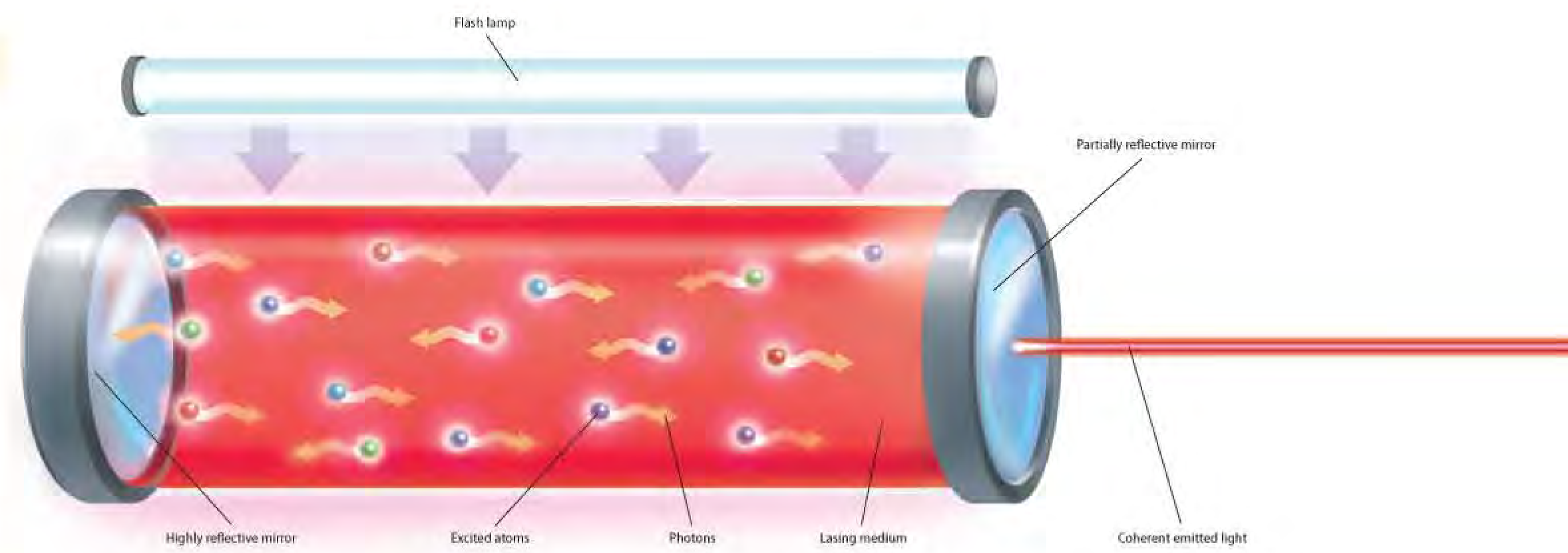
A laser's talent depends on making the atoms or molecules in the "medium" behave in exactly the same way and all exactly in step. When stimulated, say by a flash of light, all the particles in the medium (usually atoms or molecules) release energy (in the form of light) simultaneously—in other words, all the electrons in billions of atoms drop down to a lower energy level precisely in step. That makes the light coherent, with the peaks and troughs of all the light waves lined up. And they all release precisely the same amount of energy, so that all the light given out is the one pure color. (The radiation can be invisible infrared or ultraviolet, rather than visible light, but the same properties apply.)

Coherent light has some amazing properties. It has very little tendency to spread out, unlike the beam of a torch, and so it can be focused into a very

LASERS—HOW THEY WORK

The first example of a laser was produced using a ruby rod as the lasing medium, although nowadays other media—such as carbon dioxide gas—are also used.

A flash lamp provides the initial energy that excites atoms in the lasing medium, causing them to emit photons. The photons, originally emitted in random directions, bounce back and forth between two mirrors until they are all lined up in the same direction and emitted through the partially reflective mirror as a laser beam. The resulting beam can be focused with pinpoint accuracy for a broad range of applications.



tight spot, less than a thousandth of a millimeter across. This quality makes lasers ideal for creating and then detecting the tiny marks that code information in the grooves of a CD (compact disk) or DVD (digital video disk). Every CD or DVD player or burner has a laser in it.

New Applications

One of the exciting developments in recent years has been finding ways to make lasers give out blue light. Red light is quite easy to make, and we have done that for decades, but blue is much tougher, mostly because the energy levels needed to create it are much further apart. Blue laser light can be focused even more tightly than red light, so the dots in a DVD can be even smaller and the disk can hold much more information. Coherence of light is also a vital need in modern holography, providing the technology to give an image a three-dimensional look.

Tight focusing allows a laser to deliver its energy into a tiny area, able, say, to burn minute and perfectly formed holes or to shape metal parts very precisely. So high-powered lasers, often using carbon dioxide to make the infrared (heat) laser radiation, have an important role in precision engineering. There has been talk that armies might one day employ high-powered lasers as "death rays."

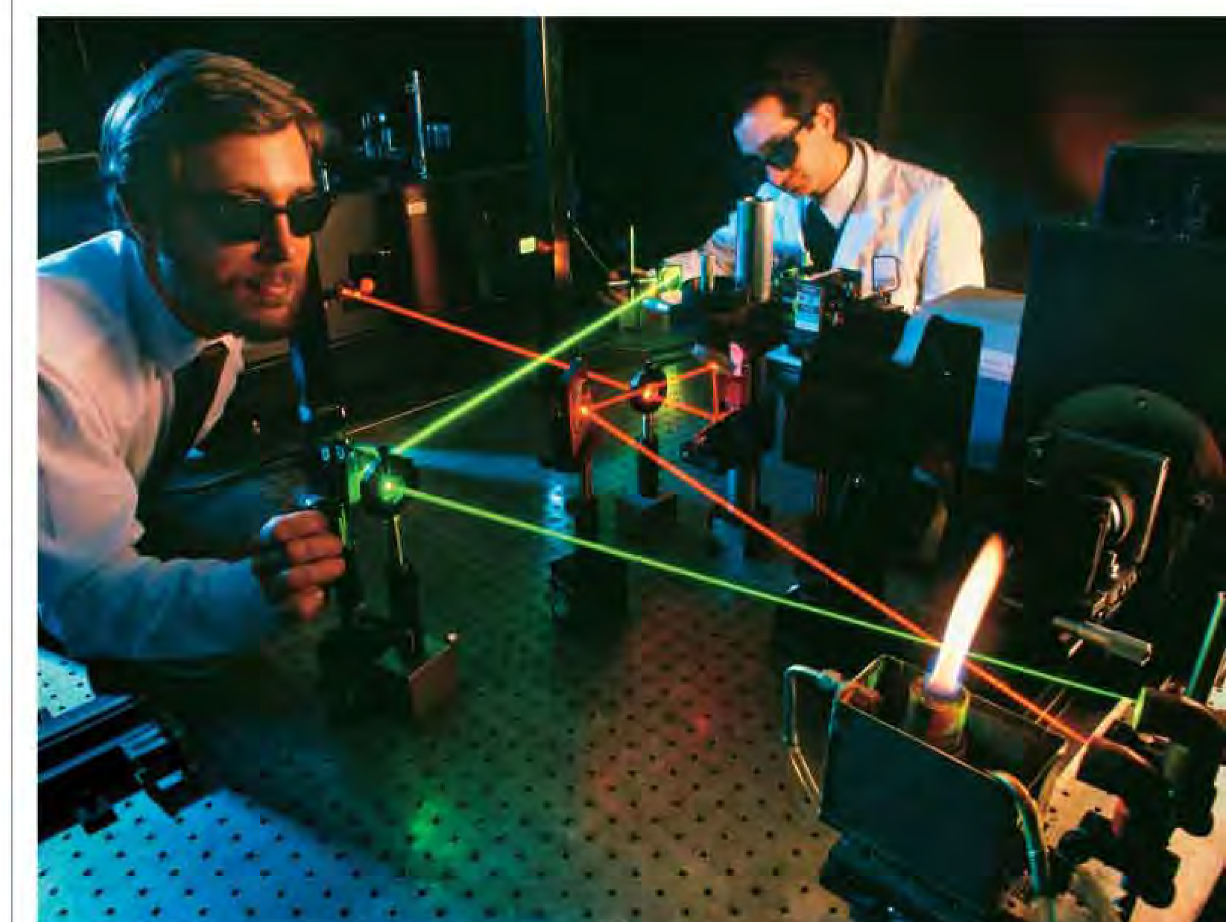
The precise color of a laser beam means that many can be sent together down an optic fiber without confusion—significantly increasing the fiber's capacity to carry data coded as tiny lumps of radiation. The popular "colors" used in optic fibers are in the infrared range, a bit lower in frequency than red light, since those frequencies encounter the least resistance as they push through the glass in the fiber. Nowadays lasers can be made very small, using the same manufacturing methods that give us computer chips, so the equipment is extremely compact.

Researchers are now investigating ways to use laser light to carry information around inside computers instead of using electric currents. This technology is called photonics, and it is likely to revolutionize computers yet again, making them even more powerful and useful.

Laser radiation also lets us measure distances with great accuracy, by timing how long a pulse of laser light takes to travel there and back. Most likely, your builder or carpenter now uses a laser device to measure up the job. By bouncing a laser beam off orbiting satellites, we now know for certain that the continents are moving relative to each other at a few centimeters a year—the phenomenon known as continental drift. Meanwhile, laser signals being bounced back to Earth by reflectors left on the Moon by the Apollo program astronauts reveal to us that the Moon is steadily moving further away by a few yards (meters) a year, slowing the spin of our planet by a few milliseconds as it departs.

Lasers have many powerful applications, transforming much of technology and adding greatly to our scientific knowledge. But back in 1960, Theodore Maiman and his colleagues at Hughes Research were not thinking about the potential applications for this device, they just wanted the laser to work.

Above: More than ten million laser eye surgery procedures have been performed worldwide, and lasers are also used in cosmetic and plastic surgery, dentistry, and podiatry.



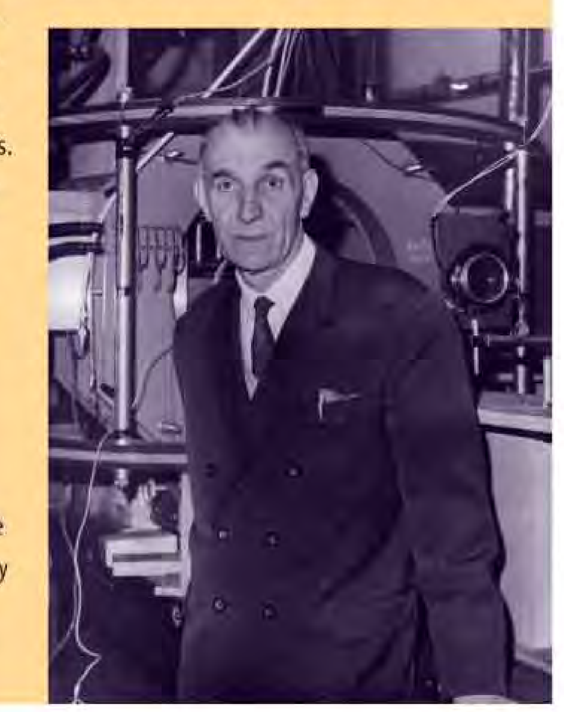
Right: Lasers are being used in an amazing variety of research areas, from air pollution to energy generation, optics to communications, and weaponry to surgery.

Above: The world's first electrically powered hybrid silicon laser chip was produced by Intel in 2006. Photonic devices like this are expected to allow computers to become faster.

MASERS—THE MICROWAVE LASER

Before we had lasers we had masers. All the letters means the same, except for the "m" which stand for "microwaves," a variety of radio waves like the ones used in a microwave oven. With all the benefits of coherence, masers soon had a major role in radio communications. Soon afterward, radio astronomers were fascinated to find very pure and precise radio signals coming from space, apparently generated by natural masers hiding in vast clouds of gas among the stars.

This discovery allowed scientists to determine what chemicals are lurking in those clouds, since each chemical emits its own distinctive radiation, and also what the temperature is out there.



Right: Physicist Albert Kastler developed the process of optical pumping to raise the energy level of an atom. This was essential to the development of the maser and the laser.

The atomic theory of matter was first postulated by ancient Greek philosophers, in particular by Democritus (born 460 BCE). He held that the atoms (from the Greek, meaning "indivisible")—of which the universe is composed—are eternal, but the bodies containing the various types of atoms decay and perish.

Nuclear Know-How

Background

In the seventeenth century, Isaac Newton reiterated Democritus's hypothesis: "The atoms do not wear out or break in pieces, no ordinary power being able to divide what God Himself made one in the first creation." In 1802, John Dalton enshrined the law of the indestructibility of matter as the first postulate of his atomic theory, namely: "Matter can neither be created nor destroyed." The belief that matter is indestructible suggested that heat and light have no mass. Along with the law of the conservation of mass stands the law of the conservation of energy, implying that mass and energy are two distinct separate entities.

Albert Einstein

In 1905, Albert Einstein, a scientist in the patent office at Bern, Switzerland, wrote four papers for the leading German physics journal, *Annalen der Physik*.

In his third paper, proceeding from the observation that the velocity of light was independent of the effects of motion, Einstein developed the Theory of Special Relativity. Any measurement of the velocity of light will always be 186,300 miles per second [299,820,787 meters per second] in any inertial frame.

In his next paper, Einstein took a bold step. He was convinced that the momentum of colliding bodies is always conserved as required by Newton's laws of motion. To maintain this position he was required by his Theory of Special Relativity to postulate that the mass of a moving body depends on its velocity. From this postulate he derived the following relationship between the mass of a body at rest, m_0; and its mass, m; moving at a velocity, v; with c the velocity of light. This relationship is known as the relativistic mass formula:

$$m=m_0/[1-(v/c)^2]^{1/2}$$

The effect is undetectable at ordinary velocities, but as the object approaches the velocity of light the mass increases without limit.

Einstein was able to show that the relativistic mass is a direct measure of the total energy of a body. This is the famous mass-energy equivalence formula:

$$E=mc^2$$

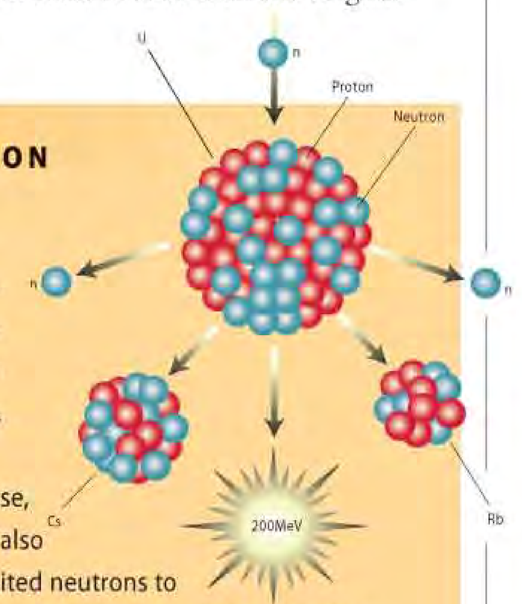
where E represents the energy, m the mass, and c the velocity of light.

It follows that if a body emits a certain amount of energy, then the mass of that body must decrease by a proportionate amount.

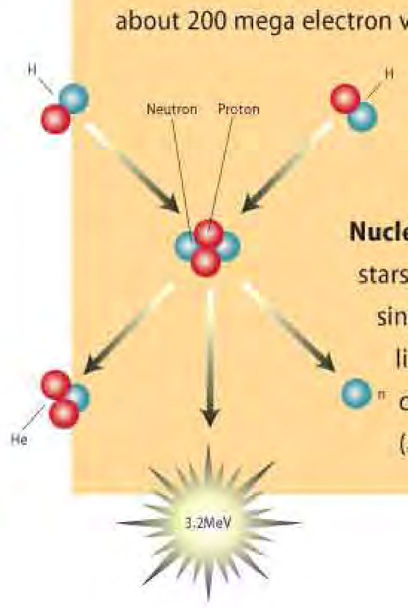
Confirmation of this relationship was slow in coming. In Paris in 1933, chemistry researchers Irène and Frédéric Joliot-Curie were able to photograph the conversion of energy into mass.

In Cambridge in 1932, John Cockcroft and Ernest Walton had observed the reverse process, the conversion of mass into energy. They broke apart an atom and found that the fragments had slightly less mass in total than the original atom. In the process, energy was released.

NUCLEAR FISSION AND FUSION



Nuclear fission occurs when a metal atom with a large atomic weight, such as uranium (U), splits into two atoms of different metals with smaller atomic weights, such as cesium (Cs) and rubidium (Rb). The splitting process, initiated by an excited neutron hitting the atom, causes the release of energy: in this case, about 200 mega electron volts. The reaction also causes more excited neutrons to be emitted, some of which may collide with other nearby atoms and set off a fission chain reaction.



Nuclear fusion is the reaction that powers our Sun and other stars. At very high temperatures, hydrogen (H) atoms, with a single proton in the nucleus, smash together to form helium (He) atoms. As in the process of nuclear fission, the collision causes the emission of a small amount of energy (about 3.2 mega electron volts) and an excited neutron.

Above: German-born Swiss citizen Albert Einstein was only 26 years old when he developed the formula for which he is best known.

Opposite page inset: When an atomic bomb was dropped on Hiroshima on August 6, 1945, almost all the buildings within 1 mile (1.6 km) of the impact point were flattened.

Opposite page: The United States conducted more than 900 nuclear weapon tests at its Nevada Test Site from 1951 to 1962. This bomb was the equivalent of 10,000 tons (9,071 tonnes) of TNT.

Right: The nuclear fusion process taking place in the Sun's atmosphere periodically gives rise to violent eruptions of radiation and matter.

CHERNOBYL

The Chernobyl incident highlighted the potential dangers of certain types of nuclear power plants. In 1986, a reactor in the Chernobyl nuclear power plant in Ukraine exploded. Ironically, the cause of the explosion was a result of tests on the reactor's safety systems. During the tests, the reactor did not receive enough coolant, causing a build-up of heat in the core. Attempts to control the problem, along with the design of the reactor, were important contributory factors that led to an uncontrollable runaway reaction.

All permanent residents within an 18½ mile (30 km) radius of Chernobyl were evacuated because radiation levels in the area had become unsafe. Clouds of radioactive material extended over Ukraine, Russia, and Belarus.

The A- and H-bombs

It is in the area of nuclear processes that the mass changes are most evident. The enormous amounts of energy released by radioactive elements had been known for some time.

Thus the atomic bombs, both uranium and plutonium (fission) and hydrogen (fusion), release vast quantities of destructive energy. The fission bomb, or A-bomb, contains the radioactive isotope of uranium, uranium-235, or plutonium-239. When a critical mass of the isotope is brought together, a violent explosion occurs as the result of a chain reaction. The fusion bomb, or H-bomb, is triggered by a fission reaction, which in turn fuses the nuclei of various hydrogen isotopes to form helium nuclei. It is even more destructive.

Applications of Nuclear Energy

The fission reaction can be controlled in a nuclear reactor to generate electricity. Special nuclear reactors are used to produce important isotopes for use in medicine and industry.

Nuclear fusion is the source of energy of the stars, including the Sun. In the initial stages of a star's life, energy arises from the fusion of hydrogen into helium. The Sun has been in existence for 5 billion years and from the loss of mass, estimated from Einstein's mass-energy equivalence formula, it is estimated that it will continue in its present stage for another 5 billion years. After that the central core will fuse helium into heavier elements.

HISTORY OF THE ATOM AND NUCLEAR ENERGY

c. 400 BCE
Theory of an indivisible "atom"

1805
Discovery that atoms of each chemical element are different

1895
Discovery of X-rays

1897
Discovery of the electron

1898
Discovery of radioactive elements

1903
Theory of nuclear reactions

1905
Special Theory of Relativity

1911
Discovery of the nucleus

1927
Uncertainty principle

1932
Discovery of the neutron

1932
Splitting of the atom

1933
Particle accelerators

1939
Fission of uranium atom

1942
Controlled nuclear chain reaction

1942–45
Manhattan Project

1945
Atomic bomb

1951
Electricity from nuclear energy

1952
Hydrogen bomb

1955
Nuclear-powered submarine

1957
International Atomic Energy Agency

1986
Chernobyl reactor meltdown

In 1997, the world was stunned when Scottish scientists at Roslin Institute created the cloning of the much-celebrated sheep "Dolly." However, this amazing breakthrough generated uncertainty over the meaning of "cloning"—an umbrella term traditionally used by scientists to describe different processes for duplicating biological material. This was an astounding development as most scientists, including Dr Francis Collins, the current head of the Human Genome Project, thought that it was impossible to clone a mammal from an adult cell.

Carbon Copies

What is Cloning?

When the media reports on cloning, they are usually only talking about the type called reproductive cloning. There are, however, different types of cloning. Cloning technologies can be used for purposes other than producing the genetic twin of another organism. Here, three types are discussed—DNA or gene cloning, reproductive cloning, and so-called therapeutic cloning.

DNA or Gene Cloning

This cloning technique refers to a process whereby a DNA fragment of interest from one organism may be cloned to produce multiple copies of the gene for further study. Bacteria are most often used as host cells for a DNA fragment, but yeast and mammalian cells are also used.

Reproductive Cloning

Reproductive cloning is a process used to generate an animal that has the same nuclear DNA as another preexisting animal. Dolly the sheep was cloned by a process referred to as "somatic cell nuclear transfer" (SCNT). A single cell was taken from the udder of a mature sheep (the donor) and the nucleus of that cell, carrying the complete DNA of the donor sheep, was removed. The nucleus was then placed in an egg cell that had had its nucleus removed. The reconstructed egg containing the DNA from the donor cell was then treated with chemicals or an electrical current to stimulate cell division. Once the cloned embryo reached a suitable stage it was transferred to the uterus of another sheep, where it developed normally. Strictly speaking, Dolly is not truly an identical clone of the donor sheep. Only the clone's nuclear DNA is the same as the donor, as some of a clone's genetic makeup comes from mitochondria in the cytoplasm of the enucleated egg.

Dolly's success is truly remarkable because it showed that the genetic material from a specialized adult cell, such as an udder cell programmed to express only those genes needed by udder cells, could be reprogrammed to generate an entire new organism. Prior to the birth of Dolly, it was taken for granted by most researchers that once a cell became specialized as a liver, heart, udder, bone, or any other type of cell, the change was irreversible and other unneeded genes in the cell would become inactive.

It appears that errors or incompleteness in the reprogramming process cause the high rates of death, deformity, and disability observed among animal clones. The SCNT cloning process is very expensive and inefficient—276 attempts were necessary to produce Dolly. Since Dolly, many other animals have been cloned by somatic cell nuclear transfer, but attempts to clone certain species, such as monkeys, horses, and dogs, have been unsuccessful.

Therapeutic or Embryo Cloning

Embryo or therapeutic cloning is the production of human embryos for research. The same process (SCNT) that was used to produce Dolly could be used to produce human embryos. In therapeutic cloning, the resultant embryo is not transferred to a human female uterus to develop.

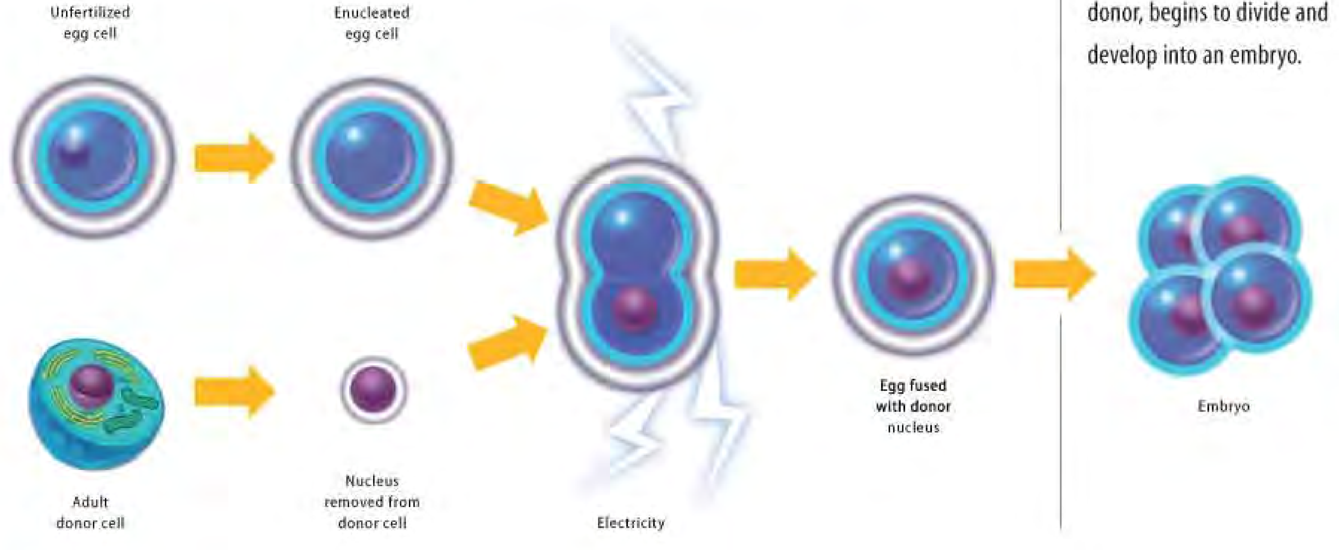
The aim of therapeutic cloning is to harvest stem cells to study human development and to treat human disease. (Stem cells are unspecialized cells that exist with the specialized cells of a particular organ. They are used by the body to repair or replace damaged specialized cells.) The stem cells are harvested just 5 days after the insertion of a donor cell into an enucleated egg. The extraction process destroys the embryo and thus raises serious ethical concerns.

Stem cells promise a cure for many diseases and traumas, but to date no successes have been reported from stem cells derived from embryo cloning. On the other hand, stem cells derived from human sources other than from the destruction of an embryo have proved more promising and have cured or alleviated many human conditions. Such stem cells are called "adult" stem cells in order to distinguish them from embryonic stem cells. They have been found in various parts of the human body, e.g. cord blood, uterus, bone marrow, and fat cells.

Right: Dolly, the cloned sheep, at home at the Roslin Institute in Edinburgh, Scotland. The research team there were the first to achieve the cloning of a mammal from an adult cell.

Facing page: A micropipette is used to inject a nucleus into an enucleated egg. Researchers at the University of Hawaii, USA, have used this technique to clone mice from adult cells, repeating the success of Dolly.

Left: Scientists at South Korea's Seoul National University present three genetically identical female Afghan hounds, produced a year after the nation's first cloning of a dog.



Below: To create a clone by nuclear transfer, an ordinary egg cell has its nucleus removed. At the same time, the nucleus of the donor cell is obtained, ready for insertion into the egg. Electricity is used to initiate chemical reactions that will fuse the two together and cause the egg to act as though it has been fertilized. The egg cell, now containing the nuclear DNA of the adult donor, begins to divide and develop into an embryo.

THE AMAZING STRUCTURE OF DNA

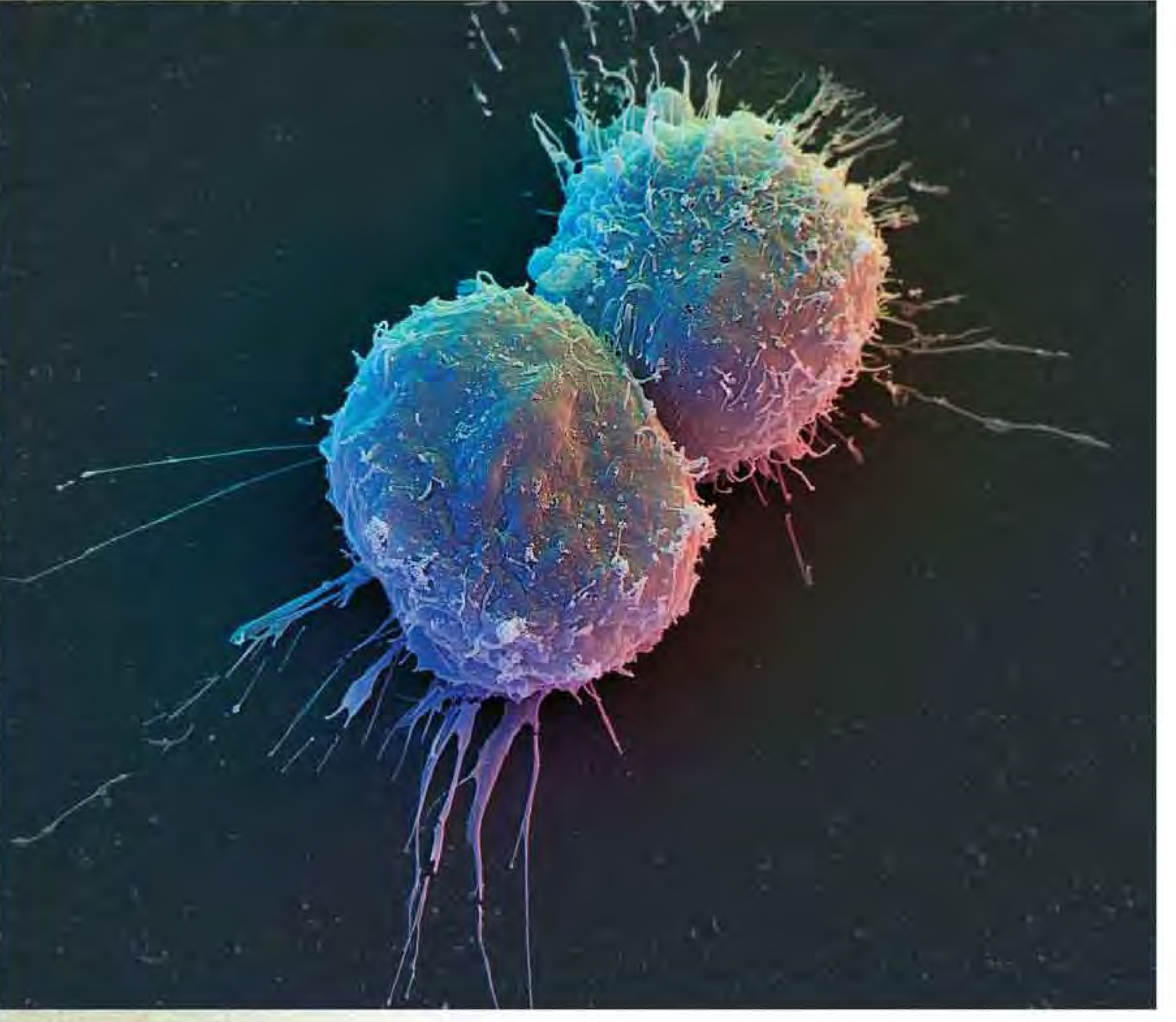
DNA is deoxyribonucleic acid and contains the genetic instructions for the development and functioning of all known living organisms. Within cells, DNA is organized into structures called chromosomes. The chromosomes within a cell make up a genome.

The DNA molecule has a number of remarkable features. The outer backbone of the double helical molecule consists of a ribbon of phosphates and sugars. But it is the interior that is truly amazing. Rungs of a ladder made up of four chemical components called bases (letters are used to denote each base) hold the double helical structure together. Each base has a different shape and thus only particular bases may form a rung of the ladder. The only compatible combinations are the following: A–T, T–A, C–G, and G–C. As will be seen, these rungs of the helical structure are able to code which amino acids will be generated for a particular protein in the cell. The mechanism whereby the DNA translates the sequence of bases into proteins is known as the genetic code. It is the proteins that do the work of the cell and provide structural integrity. It requires a combination of three of the bases A, C, T, and G to code for a particular amino acid. There are 64 possible three-letter combinations of the four bases, but there are only 20 amino acids in nature.

What is amazing is that the "genetic code" by which information in DNA is translated into protein via messenger RNA (ribonucleic acid) is identical from bacteria to humans. As the head of the human genome project remarked, "There is no Tower of Babel in the language of life."

Below: Embryonic stem cells are taken from artificially fertilized human eggs that have been donated for research. The cells are then modified in some way so that they develop into specific types of cells for use in the treatment of disease.

Above: The double helix strands of DNA. Francis Crick and James Watson from England's Cambridge University, with help from the work of Rosalind Franklin and Maurice Wilkins, discovered the structure of this basic genetic building block in 1953.



BIOLOGY