

CHAPTER 33

Medical Physics

INTRODUCTION

33.1

Discoveries in physics have played a major role in the development of medicine, especially those branches of medicine that are concerned with the use of radiant energy and nuclear isotopes in the diagnosis and treatment of disease. Improvements in microscopy techniques, such as the higher resolution of electron based microscopes, have resulted directly from the practical applications of theoretical discoveries in quantum physics.

Ever since the Nobel prize-winning discovery of the X-ray by Bavarian physicist Wilhelm Conrad Roentgen in 1895, when he produced the first X-ray of his wife's hand, diagnostic radiology or medical imaging has improved in its ability to photograph and record the internal anatomy and physiology of the human body and those of other animals. Diagnostic radiology is the imaging and analysis of both the normal anatomy and physiology of the body as well as possible abnormal effects due to disease or injury. It is usually carried out using X-ray radiographs, tomographs or computerised axial tomographs (CT scans), but other diagnostic techniques such as ultrasonics, magnetic resonance imaging (MRI), or positron emission tomography (PET) are becoming widespread.

The radiologist uses direct observation of the image obtained or extra detail can be sought with the use of various contrast media that are administered to the patient just before the radiology. Examples include upper gastrointestinal examinations (GI series), intravenous pyelograms (IVP) for the kidney and bladder, barium enemas for colon examinations, arthrograms for skeletal joints and myelograms or angiograms for the spinal cord and blood lymph vessels. These procedures allow the radiologist to record movements of organ systems internally as the contrast material flows through them in real time. The image is viewed directly on a radiation-sensitive screen (fluoroscopy), computer monitor or by recording onto videotape.

Australia possesses many nuclear medicine departments in hospitals and private facilities that use a range of medical radioactive isotopes. These isotopes are produced mainly by neutron bombardment in reactors such as at the Australian Nuclear Science and Technology Organisation (ANSTO) at Lucas Heights in Sydney. The cyclotron particle accelerator device is also used to produce short-lived isotopes, at places such as the National Medical Cyclotron (NMC) at ANSTO and the Cyclotron and PET Centre at Melbourne University's Austin Hospital and School of Physics. These facilities provide isotopes for therapeutic radiology, which is the treatment of malignant disease with ionising radiation in conjunction with drug therapy, hyperthermia and psychological counselling.

Medical physicists are those specialists who work with radiologists, oncologists, physiologists and radiographers in providing numerous practical applications of physics in the medical sciences. The understanding of basic physical principles is a necessary prerequisite for all these fields of study. In this chapter let us briefly examine the underlying principles of these diagnostic and therapeutic tools. You may need to revise previous chapters on optics, electromagnetism, quantum physics and nuclear physics.

33.2

MICROSCOPY TECHNIQUES

A microscope's resolution, or ability to distinguish small detail in a specimen, is limited by the wavelength of the light used to illuminate the specimen. In an electron microscope (EM) a beam of electrons accelerated by a high voltage (50 kV) is used instead of visible light. The de Broglie wavelength of these electrons is about 100 000 times shorter than that of light photons and so an electron microscope greatly increases the possible resolving power. Modern **transmission electron microscopes** (TEM) can resolve details down to about 0.2 nm, compared with the best optical microscopes, which resolve down to about 200 nm, with magnifications up to ten million times. The limitation for the TEM is the ability of the electrostatic and magnetic lenses to maintain good focusing. Electron microscopes need the electron beam travelling through a vacuum in order to prevent scattering by air molecules. (See Figure 33.1.) The first types were built in the 1930s.

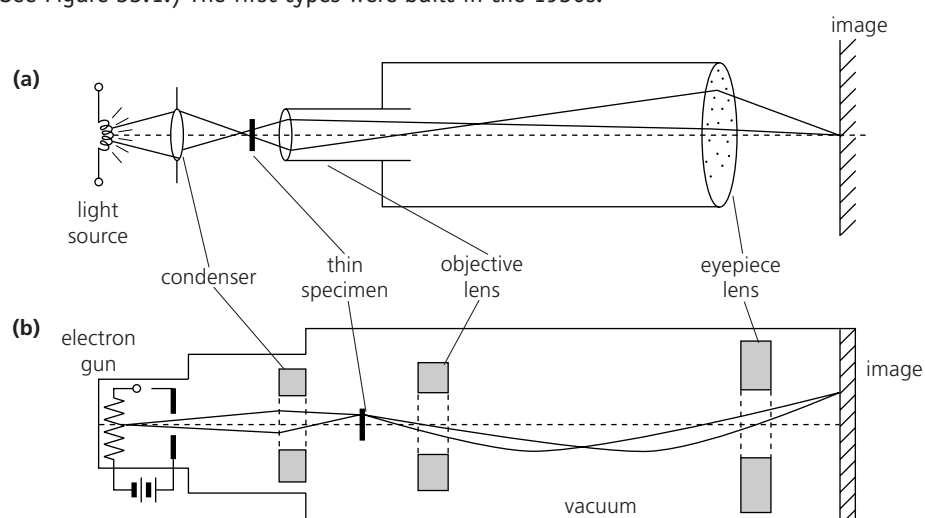


Figure 33.1
Comparison of a light microscope (a) with an electron microscope (b).

A newer instrument is called a **scanning electron microscope** (SEM) and uses a well focused beam of electrons to scan the surface of a specimen. The first practical SEM was built in 1970 by the British-born American physicist Albert Victor Crewe. The instrument is capable of producing three-dimensional images and is not really a microscope at all. The spot beam is scanned backward and forward across a specimen by the scanning magnetic field. The incident electrons cause the ejection of secondary electrons with energies typically of a few electron-volts, which are collected to form a cathode ray tube (CRT) control grid current, as shown in Figure 33.2. The sweep or timebase of the CRT is in synchronisation with

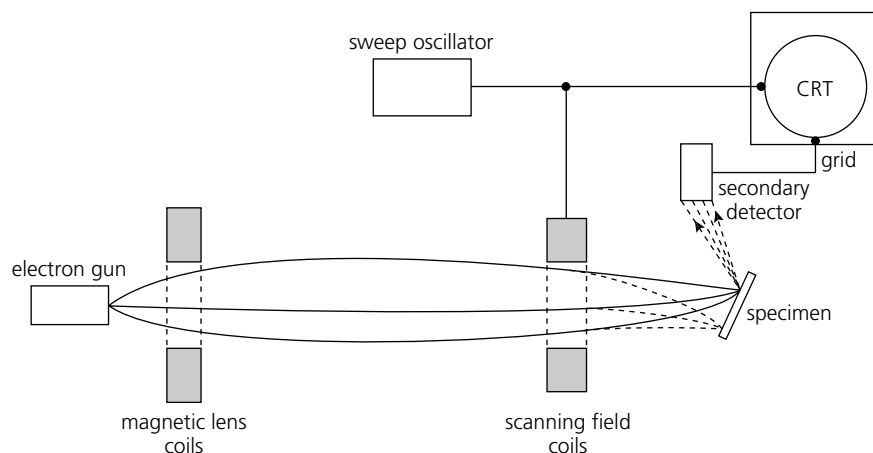
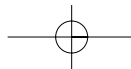


Figure 33.2
Scanning electron microscope.



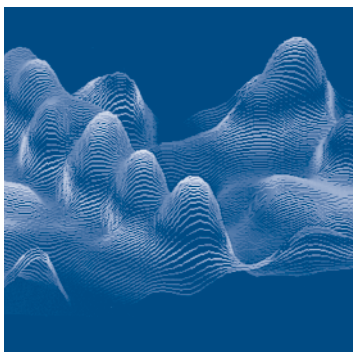
the scanning beam, and the variations in electron collector current control the CRT sweep beam brightness. The specimen is usually placed at between 30° and 60° to the incident electron beam to improve secondary ejected electron current. The resolution of an SEM is less than for a TEM, with useful magnifications extending to about 50 000 times. With an SEM, thin slices of specimen are not needed as with a TEM, with even whole living specimens able to be observed. In certain circumstances, X-rays produced due to electron collisions can be used to obtain an elemental analysis of the specimen as well. The instrument is then referred to as an **electron probe microanalyser**.

In 1986 the Nobel prize for physics was shared between Ernst Ruska, for his design of the first TEM in the 1930s, and Gerd Binnig and Heinrich Rohrer of the IBM research laboratory in Zurich, Switzerland, for designing a new kind of SEM called the **scanning tunnelling microscope (STM)**. The device relies on the quantum tunnelling effect between a scanning metal tip probe and the surface of the specimen. As the probe is moved over the surface, the flow of tunnelling electrons is kept constant by varying the height of the probe above the specimen's surface. These fluctuations in height are used to produce topographical line scans from which 3D images can be constructed. Superconducting magnetic levitation principles are used to control the height of the probe. Binnig and Rohrer were able to obtain 10 angstrom separations with their first designs. Photo 33.1 is an STM image of the oblique surface of a crystal of tantalum diselenide obtained by Professor Dan Haneman at the University of New South Wales, showing the outer electron charge contours of the lattice array of atoms.

The most recent variation of the scanning probe microscope is called the **atomic force microscope (AFM)**. The atomic force microscope does not use a tunnelling current, so the sample does not need to be able to conduct electricity. As the probe in an AFM moves over the surface of a sample, the electrons in the metal probe are repelled by the electron clouds of the atoms in the sample. As the probe moves along over the sample surface, the AFM adjusts the height of the probe to keep the force on the probe constant. An electronic sensing mechanism records the up-and-down movements of the probe, and feeds the data into a computer, which then constructs a three-dimensional image of the surface of the sample.

Photo 33.1

A scanning tunnelling micrograph.



ULTRASOUND

33.3

Sound waves above the human audible frequency range, usually 20 kHz, are called **ultrasonic waves**. Modern ultrasonic generators can produce frequencies up to several gigahertz by transforming alternating voltages or currents into mechanical oscillations, through the use of **piezoelectric** crystals.

Ultrasonic waves have long been used by living organisms, such as bats and dolphins, for echo location, and similar sonar devices are used for underwater detection and communication by submariners and boaties. In physics and engineering, ultrasonics can be used in determining properties of matter, such as compressibility and elasticity, or for fault detection in industrial materials, such as sheet metal or cast components. High vibration rates caused by ultrasonic blasting is used to clean jewellery, produce photographic emulsions and even to homogenise milk. Ultrasonics in the gigahertz range can be used to produce an ultrasonic microscope able to resolve detail to about one micron.

In the medical field, ultrasound is used as a therapeutic tool to repair damaged tissue or to treat conditions such as bursitis, arthritis or muscular damage. These applications require the ultrasound probe to produce localised heating or diathermy as a result of tissue resistance to the transmission of the waves.

Ultrasound has been used to great advantage in destroying embedded kidney stones, reducing them to small fragments that can be easily removed by catheter or passed in the urine. As a diagnostic tool, ultrasound is often more revealing than X-rays in showing the subtle density differences in cancerous tissues. It is nowadays used widely to produce foetal images from the uterus. (See Photo 33.2.) Foetal ultrasound examination was first used by Dr Ian Donald of Glasgow, Scotland, in the early 1950s. The piezoelectric crystal is housed in

Photo 33.2

Foetal ultrasound image.

