Cambridge International Examinations
Cambridge Pre-U Certificate

PHYSICS (PRINCIPAL) **9792/02**

Paper 2 Written Paper **May/June 2018**

INSERT

The question in Section 2 of this paper will relate to the subject matter in this Insert. You will have received a copy of this booklet in advance of the examination.

The extracts on the following pages are taken from a variety of sources.
Cambridge International Examinations does not necessarily endorse the reasoning expressed by the original authors, some of whom may use unconventional Physics terminology and non-SI units.

You should draw on all your knowledge of Physics when answering the questions.

This document consists of **10** printed pages and **2** blank pages.

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Extract 1: X-Rays

A modern X-ray tube is illustrated in Fig. E1.1. If very penetrating hard X-rays are required, then a high potential difference, typically 120 kV, is used between the cathode and the anode. X-ray tubes used by dentists typically use potential differences of 60 kV. A heated cathode produces electrons as in a cathode-ray tube, and these can be focussed by the shape of the cathode onto an anode. This may need to be cooled by water or oil circulated through it if the power rating is high. As the electrons hit the anode, X-rays are produced. In practice, only about 1% of the energy of the electron beam produces X-rays. The rest is wasted as heat. Tungsten, with a proton number of 74, is usually used for the anode.

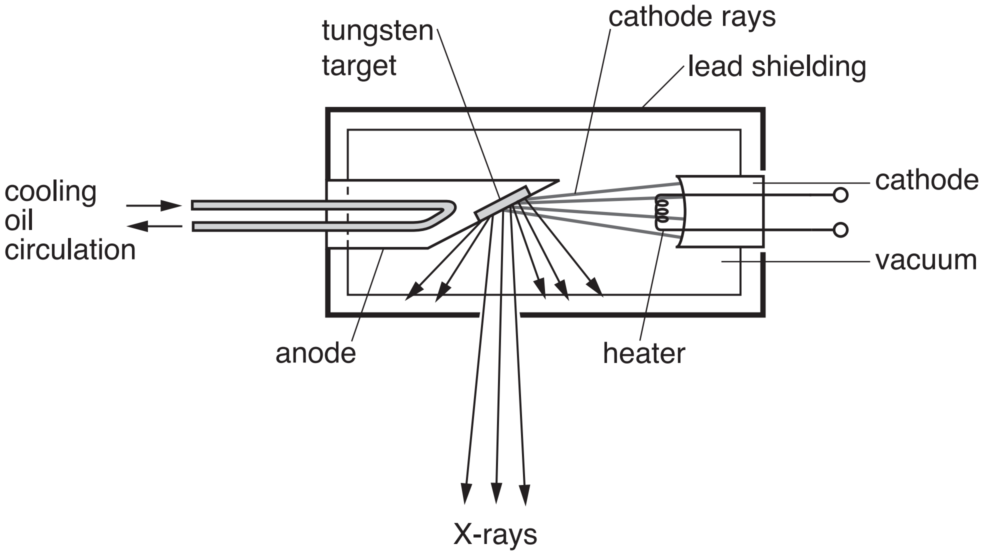
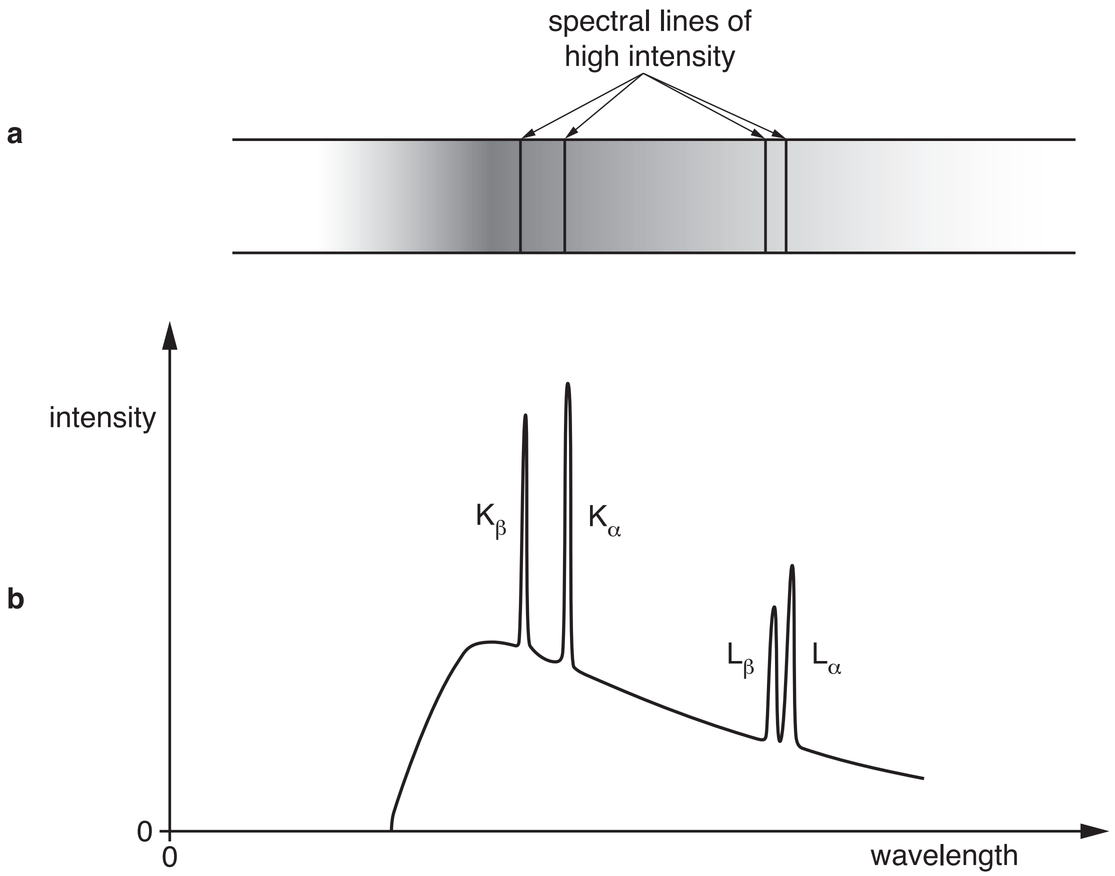


Fig. E1.1 a modern X-ray tube

When an electron strikes the target anode, its energy is not lost in creating a single X-ray photon. The electron can lose its energy in a series of encounters with target atoms or it may give several X-ray photons of lower energy. This analysis, by itself, would give rise to a continuous X-ray spectrum with a minimum possible wavelength. This continuous spectrum is found, but it is also found that there are some specific wavelengths that are much brighter.

The X-ray spectrum is both a continuous and a superimposed line spectrum, as shown in two ways in Fig. E1.2. Fig. E1.2a is a sketch of an X-ray spectrum and Fig. E1.2b is a graph showing how X-ray intensity varies with the wavelength. The wavelengths of the X-ray spectra were found to be determined by the element from which the target is made. The photon energies of the line spectra are very high so an electron within a target atom must have fallen into one of its lowest possible energy levels.



a An X-ray spectrum showing both a continuous spectrum and a superimposed line spectrum.
b A graph showing how the intensity of X-rays varies with the wavelength.

Fig. E1.2

Adapted from: Physics, Bath Advanced Science, second edition, Robert Hutchings.

Extract 2: The Attenuation of X-Rays

Attenuation and distance

If the energy of the X-rays radiates from the source in all directions, the intensity will fall in proportion to the square of the distance from the source. This arises simply from the **geometry** of the situation. The energy is spread out over the surface of a sphere; as the radius r increases from R to 2R, the area increases from $4\pi R^2$ to $4\pi(2R)^2$. Thus the intensity falls to one quarter.

$$I \propto \frac{1}{r^2}$$

This is the inverse square law for radiation. It describes the attenuation of any radiation in a vacuum and is a reasonable approximation for the attenuation of X, γ and β radiations in air.

In a medium, where absorption processes are occurring, the intensity of a beam I, falls by a constant fraction dI , through each unit distance travelled dx. That is

$$-\frac{\mathrm{d}I}{I} = \mu \,\mathrm{d}x$$

or

$$-\frac{\mathrm{d}I}{I\,\mathrm{d}x} = \mu$$

where μ is the **total linear attenuation coefficient**, a constant which depends on the medium and the photon energy of the X-rays. Integrating this differential equation gives

$$\ln I - \ln I_0 = -\mu x$$

where I_0 is the incident intensity and I is the intensity at distance x.

$$I = I_0\, \mathrm{e}^{-\mu x} \qquad \text{Equation 1}$$

This results in an exponential fall in the intensity with distance, as shown in Fig. E2.1.

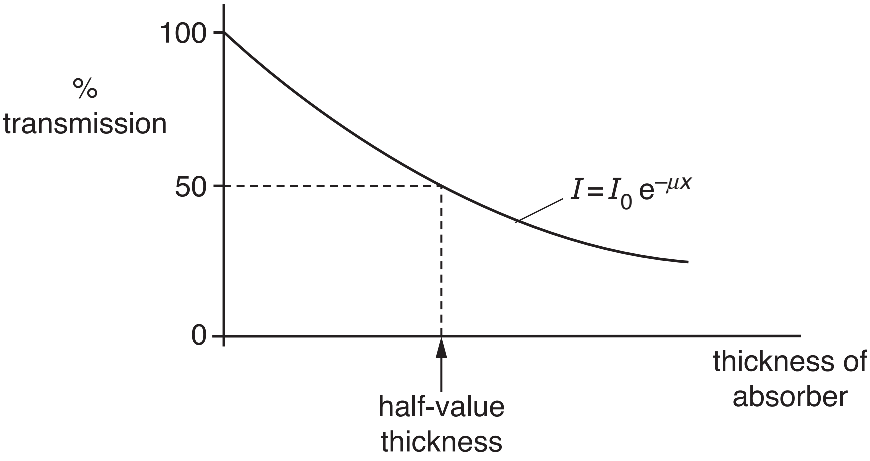


Fig. E2.1 Exponential absorption of radiation by a medium

It is useful in radiology to define the **mass attenuation coefficient** μ_m , which refers to the attenuation per unit mass of material traversed.

$$\mu_m = \frac{\mu}{\rho}$$

where ρ is the density.

The penetrating power, or quality, of a radiation can conveniently be described in terms of the thickness of material needed to reduce the intensity to half the original value. This is called the **half-value thickness (HVT)**, $x_{\frac{1}{2}}$. If we put $I = \frac{1}{2}I_0$ and $x = x_{\frac{1}{2}}$ in Equation 1, we obtain

$$x_{\frac{1}{2}} = \frac{\ln 2}{\mu} = \frac{0.693}{\mu}.$$

A beam of 80 keV X-rays has a HVT of 1 mm in copper, and a cobalt-60 gamma source (1 MeV) has a HVT of 10 mm in lead. You may be able to check the latter in the laboratory, by placing various thicknesses of lead between the cobalt-60 source and a Geiger tube and counter.

Adapted from: Medical Physics, University of Bath, Macmillan Science 16–19 Project, Martin Hollins.

Extract 3: Computed Tomography (CT) Imaging

The name CT is an abbreviated version of an older term, CAT, which stands for *computed axial tomography*. This name derives from the use of the computer in analysing a sequence of images, produced by X-rays, traversing different paths through the patient; the images themselves represent a kind of *tomography*. This latter term originates from two Greek words. These are *tomos* which means a ‘slice’ or ‘cut’ and *graphein*, which means ‘to write’ or ‘to record’. The term *slice* refers to the CT technique of recording views of many successive layers, just as a food slicer turns a 3D chunk of food into a succession of thin, essentially, 2D slices. The CT scanner, however, has the distinct advantage of not being destructive or invasive.

The basic concept of the recent sixth-generation scanner is a helical design with the detectors covering the whole of the body section. The X-ray source moves. If a long section of the body is scanned, the patient is moved slowly in a straight line, through the imaging region. Thus, in the patient’s frame of reference, the scan traverses a helical path, as seen in Fig. E3.1. Fig. E3.2 shows a photograph of an actual CT scanner.

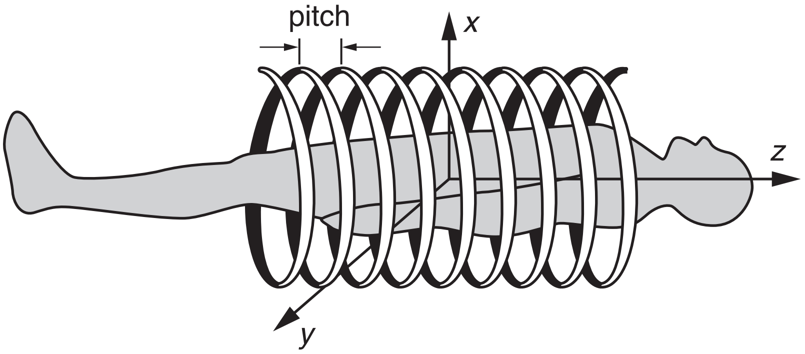


Fig. E3.1 Sixth-generation CT: helical design. The body moves gradually along the *z*-axis through the imaging region, while the source and detector revolve in the transverse plane. The scan describes the indicated helical path relative to the patient. The pitch is the distance travelled by the patient in one revolution.

Modern detectors take several slices at the same time. From the initial 4-slice machines, designs have increased up to 256-slice multidetector computed tomography (MDCT) machines. Having a large number of slices provides a critical advantage in the case of heart scans since the whole heart can be scanned during one rotation without moving the machine gantry. This greatly improves the quality of the image because the time of the measurement is significantly shorter than 1 s, a typical heartbeat’s time. It also reduces the overall X-ray exposure for this type of cardiac study. Such scans facilitate the production of film of the beating heart, which is of significant help to the diagnostician.

As an example, Fig. E3.3 shows a CT scan of the abdominal region of a woman with gallstones. The stones are clearly visible in the image, along with the other organs identified in the figure. Note that rigid structures such as ribs, vertebrae and the gallstones themselves, appear bright, whilst soft tissue appears grey or dark. The difference is associated with the absorption coefficient μ of the X-rays.

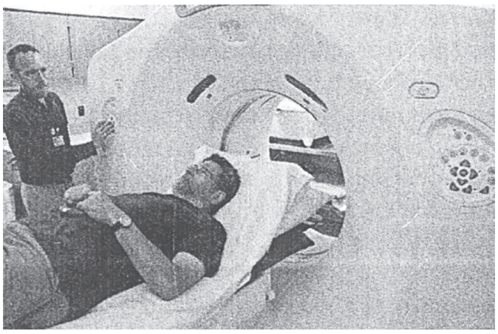


Fig. E3.2 Radiation physicist Dr. Neal Holter demonstrates the 'wide-bore' CT scanner, with large opening to permit access to patient with other equipment: GE Optima 580 RT16, where 16 refers to the number of simultaneous slices. (Photo by Dave Cole.)

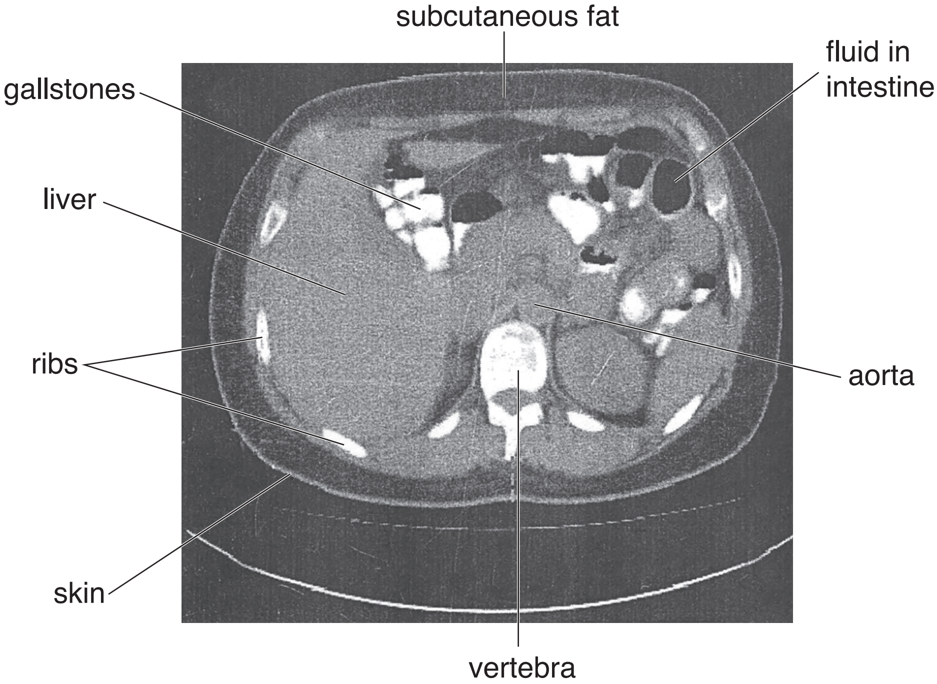


Fig. E3.3 CT scan of 'patient A'. Courtesy of Creta InterClinic, Heraklion, Greece. We gratefully acknowledge the interpretive help of Dr. Mary Callahan.

Another innovation in CT design is to employ two X-ray sources simultaneously, both mounted on the platform moving round the patient. Different initial energies of the electron beams and filters are used to form the beams with significantly different energies and a sufficiently narrow spread in energy. Since the attenuation coefficient μ, in soft tissues and bone, changes with energy, the use of two beams improves the quality of the reconstructed image.

Adapted from: Applications of Modern Physics in Medicine, Strikman, Spartalian and Cole.

Extract 4: Tamut, The Egyptian Mummy (an application of CT scanning)

Tamut's body is well preserved and CT scan analysis of her skeleton confirms that she was an adult female.

Tamut's teeth show signs of advanced dental attrition, see Fig. E4.1, and most of the crowns are very worn, almost to the roots, suggesting that she was at least thirty years old when she died. By measuring the mummy and the length of her long bones on the CT scan cross sections, it was possible to establish that she was approximately 157 cm tall.

Tamut's dental health, in spite of heavy attrition, was relatively good. Only one dental abscess was found at the end of the root of the upper-left first premolar. This abscess was the result of a chronic infection at the tip of the root. A single abscess such as this would have triggered severe inflammation, but the cause of her death is difficult to establish: evidence of disease can be hard to detect in mummified tissues.

Fig. E4.1 The scan reveals that Tamut's teeth show signs of advanced dental wear

Nonetheless, the CT images, see Fig. E4.2, revealed that the arteries in Tamut's legs are well preserved and that parts of her femoral arteries have considerable calcified plaque deposits (called atheromas). The formation of fatty plaques on the inner walls of arteries, a disease called atherosclerosis, is usually associated with a diet rich in animal fat, such as cholesterol. The calcified plaque is detectable on a CT scan, appearing as an abnormally dense layer inside the artery. The disease can cause blood clots, which in turn trigger a stroke or heart attack. Arterial plaque is increasingly being detected in ancient Egyptian mummified remains.

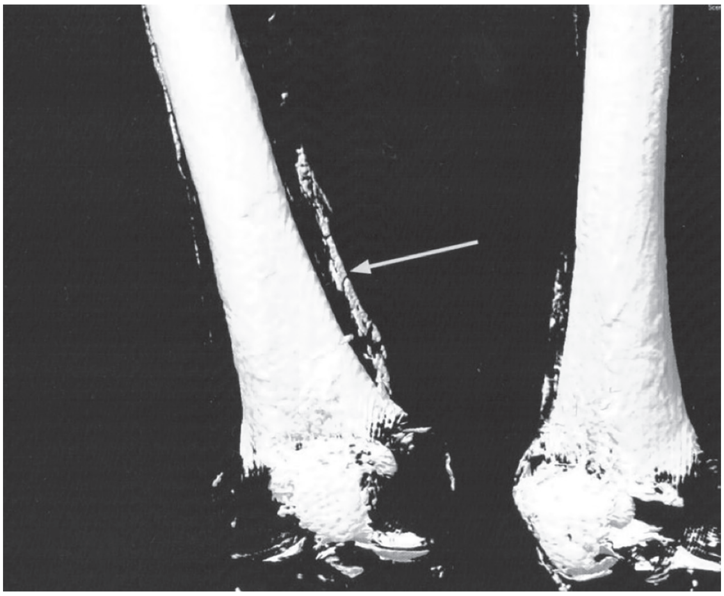


Fig. E4.2 Calcified plaque deposits found in Tamut's left femoral artery (see arrow)

CT scans show that Tamut received very careful treatment from her embalmer. Packing materials were used to reconstruct the shape of Tamut's nose and face. Her cheeks, nose and throat, in particular, appear to have been filled with dense materials and textile to restore the features which would have become wrinkled and distorted during desiccation. Another typical practice during this period was the placing of artificial eyes made of stone or glass into the eye sockets; these are also visible on Tamut's CT scans. See Fig. E4.3.

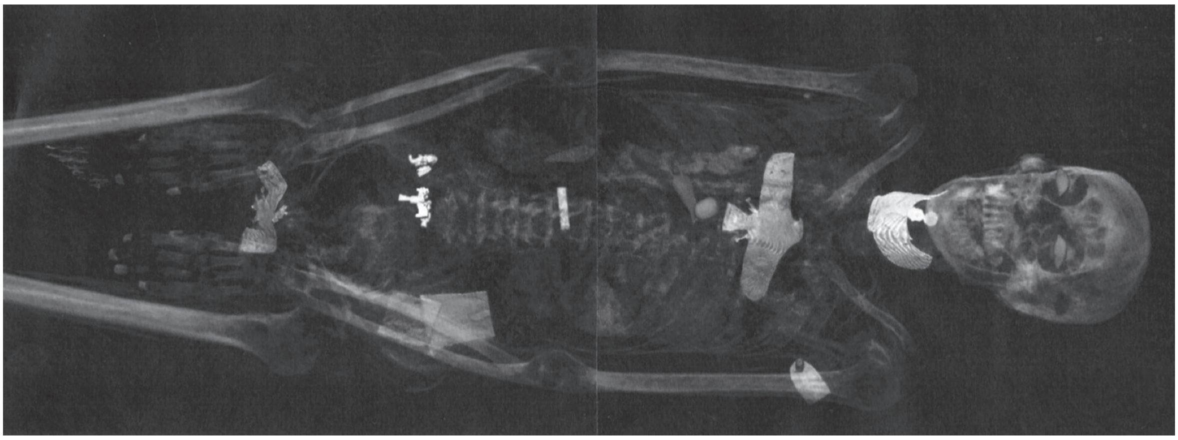


Fig. E4.3 Tamut's magical trappings. Artificial eyes, heart scarab, a bead on each arm and small amulets on the abdomen were made of faience, glass or stone. Metal objects (winged images of deities, the two incision plates, a rectangular plaque on the lower part of the chest and a plaque on the left arm) can be seen. Four wax figurines of the Sons of Horus, are positioned inside the chest cavity.

The period of about thirty-five days that was devoted to evisceration and drying constituted the first phase of purging or cleansing the body, and was aimed at removing from it all perishable parts and inhibiting the process of decomposition. The remaining period (about another thirty five days) might be called the rebuilding phase and this was the most heavily ritualised part of the process.

Tamut’s internal organs were not placed in canopic jars but were repositioned inside her chest. Each of the four bundles contained, besides an organ, a figure of one of the Sons of Horus. They can be seen on the CT scans, distinguished by their different heads.

On her fingernails and toenails are thin metal coverings, which are probably made of gold leaf. The ancient text, The Ritual of Embalming, explains that the fingers should be covered in pure gold and the nails in electrum (an alloy of gold and silver), and that these metals would regenerate and reinvigorate the deceased.

Adapted from: Ancient Lives, New Discoveries, Eight Mummies, Eight Stories. CT illustrations by Benjamin Moreno, John H Taylor and Daniel Antoine.

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