Thursday 19 June 2014 – Morning

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

INSERT

Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

- This Insert contains the article required to answer the questions in Section C.

INFORMATION FOR CANDIDATES

- This document consists of **4** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER / INVIGILATOR

- Do not send this Insert for marking; it should be retained in the centre or recycled. Please contact OCR Copyright should you wish to re-use this document.

Thermoluminescence and the monitoring of radiation dose

Exposure to ionising radiation can cause damage to living cells. It is therefore very important to be able to monitor levels of radiation and radiation dose, especially in situations where the radiation risk is high. Such places include nuclear power stations and some hospital departments, where workers might receive a dose equivalent of more than 15 mSv in a year. For many years, the main method of monitoring radiation dose used photographic film. Exposure to ionising radiation causes film to darken when developed and the greater the exposure the greater the darkening – though the range of doses that can be measured quantitatively is limited because film has a highly non-linear response to dose. This method has been superseded by Thermoluminescent Dosimetry (TLD), a very simple but reliable and robust procedure.

Flashes from crystals

Thermoluminescence (TL) is a property possessed by many crystalline materials. These materials emit light when heated after having been exposed to ionising radiation. It is a familiar phenomenon and one which has been known about for a long time. Background radiation is sufficient, for example, to produce the effect in naturally-occurring crystals like calcium fluoride, a substance used in lead-refining procedures for centuries and which glows with TL when used in this process. Modern radiation-monitoring techniques use a similar material, lithium fluoride (LiF) which has particularly suitable properties for this purpose, as we shall see.

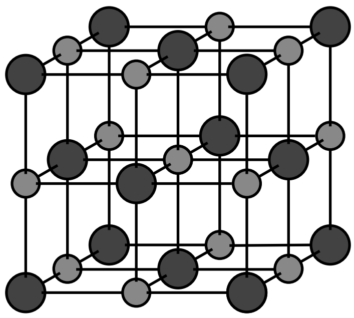

Fig. 1: cubic lattice structure of LiF

The LiF crystal structure is the same as that of sodium chloride, an ionic lattice. This makes the crystals hard but brittle and easily cleaved. For use in TL, the crystals are doped with atoms of another element, the usual one being magnesium. This creates defect sites in the crystal which have a raised energy level. If the crystal is exposed to ionising radiation, a tiny fraction (0.5%) of the radiation energy causes electrons in the crystal to be promoted to these higher energy levels where they become trapped. Typically, about 1 in every thousand atoms in the crystal will be a magnesium atom. The fraction of these defect sites at which electrons are promoted will depend on the dose. For an absorbed dose of 2 Gy this is about 1 in 10^6 for a typical crystal chip.

The electrons do naturally fall back to their original (ground) level, a process called fading. However the rate of fading is very low, typically less than 5% over a three month period. These 'trapped' promoted electrons can therefore act as an indicator of the amount of radiation to which the crystal has been exposed. To discover how many electrons were raised to the higher levels by the radiation, the crystal must be heated to around 200°C; this releases the electrons from their promoted states and as they fall back to the ground level, photons of light are emitted. An important feature of this effect is that the amount of light emitted is proportional to the amount of radiation to which the crystal was originally exposed. This linear response makes it a straightforward way of quantitatively establishing radiation doses. Moreover, unlike photographic films, the chips can be used repeatedly many times before the thermoluminescent effect becomes too small to be useful.

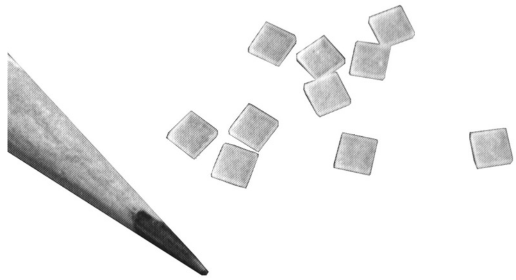

Fig. 2: some LiF chips as used in TLD, with a pencil tip for scale.

Crystals of LiF are very transparent and only slightly soluble in water. They are used in a number of physical forms but most often cleaved as individual 'chips' measuring about 3.0 mm × 2.0 mm × 1.5 mm, a form that suits most of the purposes for which they are used. Although at 2600 kg m^{-3}, the density of these LiF crystals is more than twice that of human soft tissue, the absorption of the ionising radiations (alpha, beta and gamma) is very similar. As the absorbed dose would be almost identical to the absorbed dose in the tissue of a radiation worker, this makes them very useful for dosimetry. They also cover a wide range of doses. The type shown in Fig. 2, for instance, has a specified useful range of 20 mGy to 500 Gy.

Seeing the light

The amount of light emitted during the TL process is very small so to detect it sensitive devices like photomultiplier tubes are required (see Fig. 3).

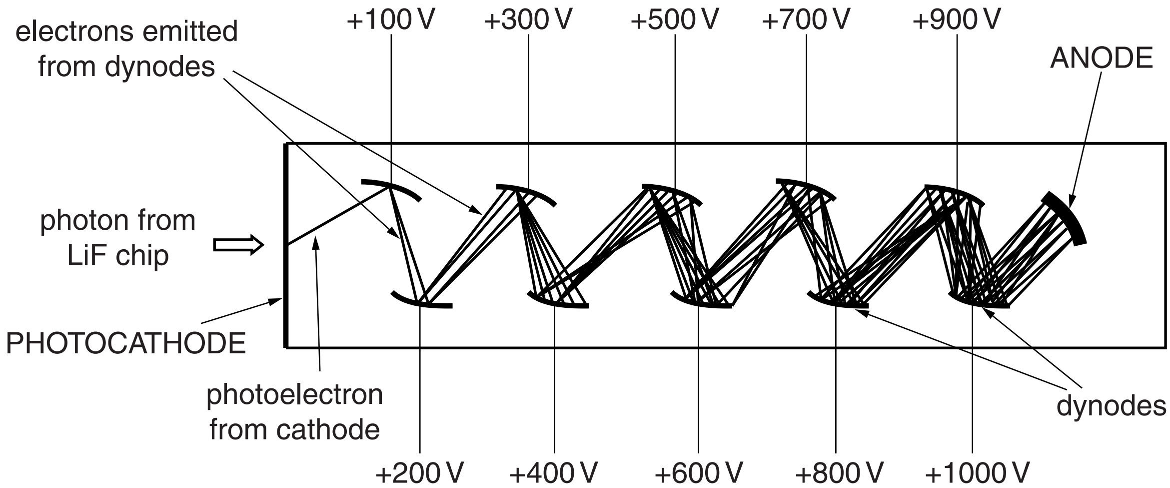

Fig. 3: schematic diagram of a photomultiplier tube

A photon from a heated LiF chip strikes the photocathode causing the emission of a photoelectron, so called because it is the photoelectric effect causing its release. This electron is then attracted to the first of a series of positive electrodes (dynodes). Upon striking the first dynode (at +100 V), this accelerated electron causes the emission of several more electrons (typically 3 or 4). These emitted electrons have negligible kinetic energy, but are accelerated to the second dynode (at +200 V). On striking this dynode, each incident electron causes the emission of 3 or 4 more electrons. In turn, these electrons are accelerated from rest to the third dynode (at +300 V), generating yet more electrons on arrival. This process continues along the length of the tube, each dynode stage resulting in a multiplication of electrons. The resulting large numbers of electrons emitted from the final dynode are attracted towards an anode at the end of the tube and a small current pulse is detected, thus registering the incident radiation that initiated the process.

The complete set of apparatus required to make use of thermoluminescence for radiation dosimetry is known as a TLD Reader, the oven (for heating the irradiated LiF chips) and the light detector (photomultiplier tube) being the main components.

TL is a powerful radiation monitoring technique: reliable, accurate, robust and straightforward. This phenomenon, known about for centuries (and mentioned by Marie Curie during some of her studies of radium) is standing the test of time and is certainly no flash in the pan.

END OF ARTICLE

