VCAA BULLETIN
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VCE Physics frequently asked questions

Unit 1 Area of Study 1: Nuclear physics and radioactivity

1. How should students use radiation weighting factors and tissue weighting factors?

Students should convert absorbed dose to equivalent dose by multiplying the absorbed dose by the radiation weighting factor/s. (Note: 'Radiation weighting factor' is of similar meaning to the superseded term 'quality factor'.)

Students should convert equivalent dose to effective dose by multiplying the equivalent dose by the tissue weighting factor/s.

2. Where can students find up-to-date values for radiation weighting factors and tissue weighting factors?

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the federal government agency which is responsible for setting Australian radiation standards. The Australian standards set by ARPANSA can be found by reading the PDF document Radiation Protection Series No. 1 (RPS 1) at: www.arpansa.gov.au/Publications/codes/rps1.cfm

Students should note that although *RPS 1* (which is based on *ICRP publication 60**) is still the basis of legislation in Victoria, *ICRP publication 60* has been replaced by *ICRP publication 103*. The latter publication contains different radiation weighting factors and tissue weighting factors from the former publication. Victoria's regulations 'define' these two factors without specifying a source for the factors, as they are considered, legally, 'terms of art'. As such, the radiation and tissue weighting factors that apply in Victoria are the most up-to-date ones, i.e. the ones contained in *ICRP publication 103* (despite the fact that RPS 1 is based on ICRP publication 60).

**ICRP publication 60* contains the main recommendations of the International Commission on Radiological Protection, including radiation protection philosophy, radiation weighting factors, tissue weighting factors and dose limits.

Unit 3 Detailed study 3.1: Einstein's Special Relativity

1. How much detail is required in relation to the prediction from Maxwell's equations about the speed of light?

No mathematical detail is required. Students should understand that Maxwell used the known laws of electromagnetism to deduce that electromagnetic fields would propagate through space at a speed related only to the force constants for electricity and magnetism. This speed was the speed of light. It was therefore deduced that light was an electromagnetic wave.

Students should recognise that the equations made no allowance for motion of the source or observer relative to the medium (unlike other known waves). This did not make sense and it was thought that some sort of error with Maxwell's equations would be discovered. The most popular theory was that light moved through a medium (the aether) that was yet to be found. This was the main reason Michelson and Morley performed their famous experiment.

2. Which comparisons should students make between the predictions from Maxwell's equations and the classical principle of relativity?

Students should be aware that Maxwell's equations implied that light should have an absolute velocity independent of the frame of reference and that this was in complete contradiction to the classical principle of relativity (also known as Galilean relativity). That principle implies that the measured speed of light must be dependent on the velocity of the observer's frame of reference. In particular, the speed measured by the observer should be relative to the observer's velocity through the medium in which the light is travelling.

3. In what way was Einstein's first postulate an extension of the classical principle of relativity?

According to classical relativity, the laws of physics relating to mechanical phenomena were quite independent of the (inertial) frame of reference chosen. On the other hand, some of the laws of electromagnetism appeared to be in contradiction to this principle. The first postulate is a statement by Einstein that the laws of electromagnetism (including, therefore, the laws that related to light) should also be consistent with the well established principle of relativity.

4. How did Einstein's second postulate compare with classical physics?

The second postulate was in complete contradiction to classical physics which held that the velocity of anything depended on the frame of reference in which it was measured. While it was not surprising that the velocity of light should not depend on the velocity of the source, according to classical physics the measured velocity of light should certainly depend on the velocity of the observer relative to the medium through which the light was travelling.

5. To what extent should students know the details of the Michelson-Morley experiment?

It is sufficient that students know that the experiment attempted to measure the difference in the speed of light in two directions at right angles to each other. They should understand that as the Earth was considered to be moving through the hypothetical aether it was expected that there would be a small difference in the measured speed of light in the direction of the Earth’s motion as compared to the direction at right angles to the motion. Knowledge of the details of the experimental setup is not required for the purposes of this Detailed study.

The result of importance for students is that no difference in the speed of light in the two different directions was found. This implied no support for the aether hypothesis but supported Einstein’s postulate that the speed of light would not depend on the motion of the observer.

6. What type of ‘thought experiments’ should students consider?

Since it is not possible to perform experiments with normal objects at very high speeds, students should understand that Einstein (and many commentators since) used the notion of ‘thought experiments’ to illustrate the implications of Special Relativity. In these experiments Einstein’s two postulates are applied in situations which can be thought about but not achieved in reality (such as in spaceships or trains moving at very high speeds) to visualise concepts including time dilation and length contraction. Examples of selected thought experiments will be available in the Physics section of the ‘VCE Studies and Resources’ link on the VCAA website.

Students should understand that ‘thought experiments’ usually consist of considerations of the different time intervals or length measurements between ‘events’ as recorded by observers in different frames of reference. An ‘event’ may be defined as a thing that happens at a certain time and place (such as Einstein’s lightning flashes).

In considering ‘thought experiments’ students should remember that effects due to the ‘look-back time’ (i.e. the time for light to travel from an event to our eyes) are not relativistic effects. In the common ‘lightning flash train’ example, for instance, confusion can occur about when various observers ‘**saw**’ the flashes. Students should be careful about whether the reference is to the time the light from the flash actually entered the observer’s eye (generally referred to as ‘seeing’ the flash), or the time (and place) the observer deduced that the flash must have occurred in their frame, having taken into account the ‘look-back time’. Students should generally use the latter interpretation and should describe it as an event that was **observed** to have occurred at a certain time and place, with the space and time coordinates of the observation being those of the actual event.

7. Are students required to mathematically derive time dilation and length contraction equations?

No.

While teachers will often use some form of mathematical derivation to illustrate the meaning of these equations, the mathematical details of the derivation is not required for the purposes of this Detailed study. Students should, however, understand that these expressions follow from Einstein’s two postulates. It is also important that students understand that time dilation and length contraction are not ‘optical illusions’ due to ‘look-back time’ effects. Students should take ‘look-back time’ effects into account before applying time dilation and length contraction equations.

8. Are students required to establish the total mass-energy relation from first principles?

No.

It is sufficient that students realise that Einstein showed that this expression was a consequence of his postulates. Students should understand that the two expressions $E_{tot} = E_k + E_{rest} = mc^2$ and $E_k = (\gamma - 1)m_oc^2$ are equivalent, as demonstrated through the substitution $E_k = (\gamma - 1)m_oc^2 = m_o\gamma c^2 - m_oc^2 = mc^2 - m_oc^2 = E_{tot} - E_{rest}$. In the expression $m = m_o\gamma$, students should always refer to the m as the ‘relativistic mass’ (rather than the ‘mass’), as it is a construct which helps understand why the inertia of a body increases as gamma increases. In addition, students should note that at velocities significantly less than c the expression $E_k = (\gamma - 1)m_oc^2$ reduces to $E_k = \frac{1}{2}mv^2$.

9. In what sense are mass and energy equivalent?

In nuclear reactions (or *any* reactions) a small amount of mass may seem to ‘disappear’ while a large amount of energy may seem to ‘appear’. Students should understand that it is not that the various sub-atomic particles get lighter but rather that the total nuclear mass has decreased due to the loss of potential energy associated with the forces between the nucleons. Just as an apple loses potential energy, but releases kinetic energy, when it falls to the ground, so the nucleons in the nucleus release kinetic energy (mostly as heat energy), as they become more tightly bound.

Students should understand that the difference between the apple falling and the nuclear reaction is that, relatively speaking, the amount of energy involved in the nuclear reaction is huge. From Einstein’s equation, mass is associated with energy. In the case of the apple falling, that mass is virtually impossible to measure. In nuclear reactions the mass is significant and measurable and hence mass seems to ‘disappear’ in a nuclear fission reaction.

10. Why can’t a continuous force accelerate a spaceship to faster than the speed of light?

While students can use the time dilation and length contraction equations to show why nothing can exceed the speed of light (time would stop and length would contract to nothing), students should use the $m = m_o\gamma$ equation to consider the question ‘why can’t we just keep accelerating past c?’ In determining the acceleration of an object from Newton’s law students should use the relativistic mass m (not m_o). Since this increases to infinity as the speed of light is approached, students should understand that no force can accelerate the object up to c, much less beyond it.

Unit 4 Detailed study 3.1: Synchrotron and its applications

1. How deeply should students be able to explain the production of electromagnetic radiation?

The simple statement at the end of the first dot point provides sufficient detail.

From the study of Unit 4 *Electric power*, students should be aware of Faraday’s law of magnetic induction that a changing magnetic field induces an emf, also described as a voltage drop or a potential difference. They will understand that a potential difference causes charge to move. They will now need to appreciate that this causing of the movement of charge can also be explained by the concept of an electric field, and that an electric field is a property of space, in the same way as a magnetic field.

Students should understand that an electron has an electric field in the space around it such that if another charge is placed in that field, it will experience a force, and when an electron is accelerated, its electric field is affected.

As a consequence of Maxwell's equations, a changing electric field produces a changing magnetic field, and from Faraday's law, this changing magnetic field induces a repeatedly changing electric field, and so producing electromagnetic radiation.

2. Do students need to know Maxwell's equations?

No.

3. How does the production of synchrotron radiation differ from other methods of producing electromagnetic radiation?

Electromagnetic radiation is produced in a number of ways: the acceleration of charged particles by an electric and/or magnetic field, the transition of electrons or nucleons from one energy level to another within an atom, the annihilation of a particle with its anti-particle. Synchrotron radiation is electromagnetic radiation produced by the acceleration of very fast moving electrons in magnetic fields. When electromagnetic radiation is produced by accelerating slow moving electrons (e.g. electrons in a radio transmitter) electromagnetic waves are emitted in 'all directions'. However, relativistic effects result in synchrotron radiation being shaped into a narrow beam (a cone) along a tangent to the curved path of the electron.

4. What do students need to know about electric fields?

An electric field is a property of the space around a charge such that if another charge is placed in that field, it will experience a force (compare with magnetic and gravitational fields).

Electric field is a vector quantity. The direction of an electric field is given by the direction a positive charge would move.

The unit for electric field strength is Newton/coulomb and an equivalent unit is Volt/metre (compare with N/kg and m/s^2 for gravitational field strength).

Parallel plates with a voltage across them produce a uniform electric field, whose strength is given by: (potential difference divided by plate separation, $E = \Delta V/d$).

5. Which equations should be used to analyse electron acceleration?

The acceleration of an electron should be analysed using the general relationship, $F = qE$. In addition, an alternative expression for the force on a charge between parallel plates ($F = qV/d$), and an expression for the gain in kinetic energy ($\Delta E_k = Vq$) may be used in analysing electron acceleration specifically in an electron gun.

6. Why are there no equations associated with the design of the Australian Synchrotron and the general purpose of the nominated components?

Since the electrons are travelling at very close to the speed of light, a more complete description of the behaviour of electrons in the various electric and magnetic fields within the actual linac, booster and storage rings would require competence with the equations of the theory of Special Relativity. This is not required in this Detailed study.

7. Is synchrotron light always 'better' than other forms of light?

Not necessarily. Synchrotron light has many advantages over other forms of light, but depending on its required use it may not always be necessarily 'better'. In addition, it should be acknowledged that with the expenditure of sufficient funds and the development of new technologies, free electron lasers and/or x-ray sources can be developed to exceed synchrotron radiation in one or more aspects, although students are not expected to be aware of such initiatives.

For the purposes of this Detailed study, however, students are expected to limit the comparison of synchrotron light to light from conventional, readily available sources (i.e. laser light and x-ray tubes).

8. How is the radiation 'tuned' in a beamline?

The synchrotron radiation from the storage ring has a very broad spectrum. While some sections of the spectrum can be filtered out, the end user wants a single frequency with a very precisely known value. To achieve this, the broad spectrum needs to be 'tuned', just as a radio needs to be tuned to a particular frequency to hear a chosen station.

In the case of a beamline, this tuning is done by a device called a 'monochromator', which produces only one wavelength of X-ray. For the purposes of this Detailed study, it is only necessary for students to consider that this is achieved by a single deflection crystal monochromator where the beam meets a precisely cut crystal of silicon. Bragg's Law can be applied to show that each frequency will emerge at a particular angle.

9. How does the process of the photoelectric effect differ for visible light and X-rays?

As described by Einstein, the actual process of the photoelectric effect is identical for both visible light and X-rays. However, the wavelength of X-rays is significantly less than that of visible light. This means that long wavelength electromagnetic radiation (i.e. visible light) may be used to probe the outer shell electronic structure of atoms while shorter wavelength electromagnetic radiation (i.e. X-rays) can be used to probe the inner shell electrons.

Published by

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