BELMONT CITY COLLEGE
YEAR 12 PHYSICS

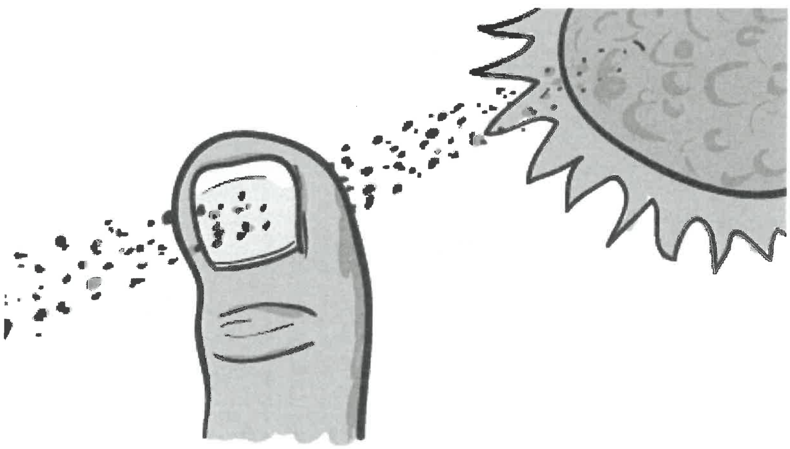
EVALUATION AND ANALYSIS
MODERN PHYSICS, 2022

Name: Solutions   Marks: /42

INSTRUCTIONS TO CANDIDATES

Allowed time: 55 mins

- Answer all questions in the spaces provided.
- Give numerical answers to an **appropriate number of significant figures (not necessarily 3).**
- Credit may be obtained for method and working out despite an incorrect final answer, providing your solution to the problem is clearly set out.



FACT: about 65 million neutrinos pass through your thumbnail every second.

1. There are three types of neutrino. List them. (1 mark)

Electron, Muon & Tau

2. What is 'neutrino oscillation'? (1 mark)

Neutrinos change from one type (flavour) to another eg. muon neutrino to electron neutrino

3. Explain why neutrino oscillation might be the key for an explanation for why there is more matter than anti-matter in the universe. (2 marks)

If the oscillations of neutrinos are different to those of antineutrinos, (1) it would be an example of charge-parity violation, creating more neutrinos than anti-neutrinos. (1)

4. How are the neutrinos detected? Summarise the operation of the T2K Super-Kamiokande neutrino detector. (only the Super-Kamiokande **detector** – not the whole experiment) (2 marks)

Neutrinos pass through ~ 50000 tonnes of ultra-pure water surrounded by sensitive optical detectors. (1) Very rare interactions between neutrinos & water produce faint flashes of light. (1)

5. Why does so much water need to be used in the neutrino detector? (1 mark)

Interactions between neutrinos & water are rare; more water means more opportunity for an interaction to occur & be detected.

6. Briefly explain Hubble's Law. (2 marks)

The further a star or galaxy is away from us, (1) the faster it is travelling/receding. (1)
("Describes how Universe is expanding" – only 1 mark).

7. Why does the Hubble Constant change? (2 marks)

The Hubble Constant is constant throughout space, but varies over time. (1) Since light from distant stars came from a much earlier time, its' Hubble Constant is different from the closer stars.

8. How do astronomers measure the velocity of stars or galaxies relative to us? (2 marks)

Red-shift (Doppler shift) (1) – when comparing spectra from stars to spectra from a lab, all λ will be observed as being shifted for known elements. Velocity can be calculated from the degree of shifting (1).

9. State three methods astronomers use to measure the distance to distant stars or galaxies. Briefly explain each. (6 marks)

(i) Parallax (1) for close stars – the amount they move against background is used to measure an angle, then distance is calculated using simple trig. (1)

(ii) Cepheid Variable Stars (1) pulsate; true brightness is calculated from the period of pulses. By comparing to apparent brightness, distance can be calculated. (1)

(iii) Type Ia Supernovae (1) "standard candle"; bright enough even for distant galaxies. Again, compare true or absolute brightness to apparent brightness and calculate distance. (1)

10. Synchrotrons and other particle accelerators are essentially similar devices, but with different purposes. Synchrotrons accelerate charged particles to produce 'synchrotron light' and other particle accelerators accelerate particles to produce collisions.

a. Why is it not really accurate to call it synchrotron 'light'? (1 mark)

Produces a range of electromagnetic radiation from Infrared to X-ray.

b. How and where in the storage ring is the synchrotron light produced? (2 marks)

Bending electrons in circular path produces E.M. radiation. (1) Occurs between the strong electromagnets. (1)

c. List two special characteristics of synchrotron light that make it useful for researchers (1 mark)

Brightness (1)

Can be tuned to a specific wavelength (1)

11. The linear accelerator stage at the Australian Synchrotron accelerates electrons to an energy of 100 MeV in 10 metres.

a. Using **Newtonian physics** only, calculate the speed of the electrons after this acceleration. (3 marks)

$$100 \text{ MeV} = 100 \times 10^{6} \times (1.6 \times 10^{-19}) = 1.6 \times 10^{-11} \text{ J} \quad (1)$$

$$E_k = \frac{1}{2} M v^2 \Rightarrow V = \sqrt{\frac{2E_k}{M}}$$

$$V = \sqrt{\frac{2 \times (1.6 \times 10^{-11})}{9.11 \times 10^{-31}}} \quad (1)$$

$$\boxed{V = 5.93 \times 10^{9} \text{ M/S}} \quad (1)$$

b. Use your answer to justify whether or not it is reasonable to ignore relativistic effects at an electron energy of 100 MeV as you did in the calculation in part (a) (1 marks)

Ignoring relativistic effects yields a speed greater than the speed of light ; this is not reasonable.

c. Repeat the calculation you did in a, this time using the expression for relativistic energy in your data sheet. Report your answer as a multiple of c, with as many significant figures as possible. (3 marks)

$$E = \gamma m_0 c^2$$

$$\therefore 1.6 \times 10^{-11} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \times (9.11 \times 10^{-31}) \times (3 \times 10^8)^2$$ (1)

$$\therefore \sqrt{1-\frac{v^2}{c^2}} = 0.005124375$$

$$\therefore 1-\frac{v^2}{c^2} = 2.625921914 \times 10^{-5}$$ (1)

$$\therefore v^2 = 0.999973740 8\, c^2$$

$$\boxed{v = 0.9999868703\, c \quad \text{or} \quad 2.99996061 \times 10^8 \text{ m/s}}$$ (1)

12. Superconducting electromagnets are used to 'steer' the charged particles around the circular beam line. Explain, with reference to an equation, why:

a. Such strong magnets are needed (2 marks)

$F_B = F_c \Rightarrow Bvq = \frac{mv^2}{r}$ (1)

At large (relativistic) speeds, particles will gain mass. The centripetal force required to bend the path is increased, so the magnetic force, and therefore the magnets, must be strong. (1)

b. With consideration to your answer to part (a), why do you think very large diameter accelerators are needed to obtain the highest velocities (2 marks)

From $F_B = F_c$, $r = \frac{mv}{Bq}$ (1)

As velocity and mass increase, there will be a point when magnetic field strength is maxxed out. A large radius is therefore required to accomodate higher velocities. (1)

13. There are 4 key pieces of evidence that supports the big bang model.

Briefly describe each of them. (8 marks)

(i) - Observed Recession of Galaxies. (1)

- The relationship between distance to galaxies & recessional velocity is due to the expansion of space (Hubble's Law). Evident due to degree of redshift. (1)

(ii) - Cosmic Microwave Background Radiation (CMBR). (1)

- Remnant radiation from the Big Bang was predicted (by Gamow) then observed (by Penzias & Wilson). Radiation fits a black body spectrum. (1)

(iii) - Ratio of Primordial Elements. (1)

- The relative abundance of lighter elements observed by astronomers (through emission / absorption spectra) matches ratios predicted by the Big Bang model. (1)

(iv) - Observed Evolution of Extragalactic Objects over Cosmic Time. (1)

- More distant (older) parts of the Universe show evidence of the stages of galactic evolution. (1)

End of Test