APPLECROSS SHS
YEAR 12 PHYSICS

ASSESSMENT:

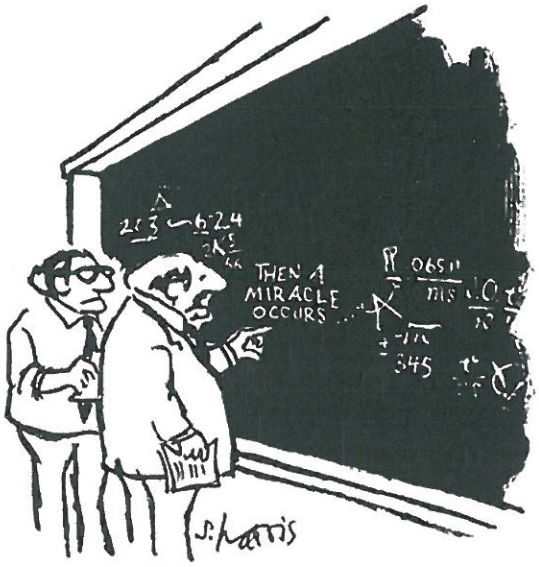
EVALUATION AND ANALYSIS
MODERN PHYSICS

Name: Solutions   Marks: / 33

INSTRUCTIONS TO CANDIDATES

Suggested time: 40 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.



"I think you should be more explicit here in step two."

QUESTIONS

Neutrino oscillation (first 2 articles)

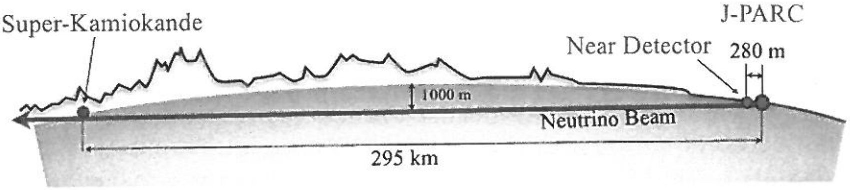
1. What are the three particles which have associated neutrinos? (1)

electron, muon, tau leptons

2. Explain in your own words why the phenomenon of neutrino oscillation may explain why there is not an equal amount of matter and antimatter in the universe. (2)

There is evidence to suggest that neutrinos & anti-neutrinos oscillate differently
Some difference in behaviour is needed to explain why one form of matter (normal) is 'favoured' over the other form (antimatter) in our universe

3. In the T2K experiment, the detector is located 295 km from the location where the beam is produced, as shown in the diagram below. What property(s) of neutrinos allows the detector to be placed so far away? (1)



Neutrinos are highly penetrative & will pass through 295 km of earth with very few interactions

4. Summarise the operation of the T2K neutrino detector (2)

Very occasionally a neutrino will interact with a water molecule.
This results in a tiny flash of light which is detected by a bank of sensitive optical sensors

5. Why does so much water need to be used in the detector? (2)

Interactions between neutrinos & matter are rare
Therefore a lot of matter (water) is needed to ensure there are occasional interactions which can be detected

The Big Bang – Articles 3 and 4

6. Two different methods of measuring the expansion of the universe are described in article 3. Explain the disagreement between these measurements and to what part of the universe each measurement applies. (2)

+ Redshift measures expansion of local/nearby universe. ✓
+ Mapping cosmic background microwave radiation measures global/large scale expansion ✓

7. Right is a picture of a spiral galaxy. Explain why the very shape of this galaxy suggests there must be something present that telescopes can't detect and what this 'something' has been named. (3)

The theory of gravitation tells physicists that stars on the outer arms should orbit more slowly than inner-orbiting stars. ✓ This would collapse the observed spiral pattern ✓. Scientists have therefore deduced that more matter must be present which is not directly detectable, which they have called 'dark matter' (½) (½)

8. Astrological data suggests that the rate of expansion of the universe is accelerating (2).
   a. Explain why this surprised scientists (1).

Gravitational attraction between galaxies should be reducing the rate of expansion. ✓

   b. What 'theory' did scientists postulate to explain this acceleration (1)?

'Dark energy' (½) is thought to somehow produce a force which counters gravity ✓

Particle accelerators and synchrotrons (the final 2 articles)

9. 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 (9)

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

   It includes wavelengths other than light ✓

   b. How and where is the synchrotron light produced (2)?

   Whenever electrons are accelerated they produce EMR ✓
   Bending magnets, wigglers, undulators provide the acceleration ✓

   c. Name two special characteristics of synchrotron light that makes it useful for researchers (1)

   Narrow band λ, controllable λ, high intensity ✓

   d. Explain why high energy collisions can produce new particles of matter which have more mass than the particles which were collided (2)

   Matter & energy are equivalent ($E=mc^2$) ✓
   The KE of the particles in the accelerator provides the energy which is converted to mass ✓

   e. The Higgs boson is the most massive particle predicted by the Standard Model. Explain why this caused it to be the last particle discovered (1).

   More massive particles required more energy (½)
   this required larger accelerator / more investment / tech (½)

   f. Explain why all types of particle accelerators must maintain a vacuum environment for the particles (1).

   Particles in the beam will interact with stationary gas particles & lose energy ✓

10. 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. (2)

$E = 100 \times 1.6 \times 10^{-13}$

$= 1.6 \times 10^{-11}$ J

$E_K = \frac{1}{2} m v^2$

$\Rightarrow v = \sqrt{\frac{2E_K}{m}}$

$= \sqrt{\frac{2 \times 1.6 \times 10^{-11}}{9.11 \times 10^{-\cancel{20}\,31}}}$

$= 5.93 \times 10^{9}$ ms^{-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)

This is > c (½), which is not possible according to the theory of special relativity (½)

11. 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)*

$E_T = \frac{mc^2}{\sqrt{1 - v^2/c^2}} = 1.6 \times 10^{-11}$

$\Rightarrow \sqrt{1 - v^2/c^2} = \frac{9.11 \times 10^{-31} \times 9 \times 10^{16}}{1.6 \times 10^{-11}}$ ✓

$\Rightarrow 1 - v^2/c^2 = 2.62592 \times 10^{-5}$ ✓

$\Rightarrow v = \underline{0.999987\,c}$ ✓

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)

$r = \frac{mv}{qB}$ ✓ Thus, for a given geometry & particle, the larger the velocity, the larger the fields needed to steer the particles ✓

$(\Rightarrow v \propto B)$

b. To achieve very high velocities, very large accelerators are needed (2)

Since the steering fields B are limited by technology & practicality ✓, to achieve the highest velocities scientists have no choice but to increase r ✓