PHYSICS

Year 12, 2011

Semester ~~One~~ Examination

SECTION C

Question/Answer Booklet

Name:

Teacher:
JAA / ICT

TIME ALLOWED FOR THIS PAPER

Reading time before commencing work: Ten minutes

Working time for paper: Three hours

EXAMINERS USE ONLY	
Section C	

MATERIAL REQUIRED/RECOMMENDED FOR THIS PAPER

TO BE PROVIDED BY THE SUPERVISOR

This Question/Answer Booklet comprising **12** pages

Data and Constants Sheet

INSTRUCTIONS TO CANDIDATES

Answers to questions involving calculations should be evaluated and given in decimal form.

Quote the final answers to no more than four significant figures.

Despite an incorrect final result, credit may be obtained for method and working, provided these are clearly and legibly set out.

Questions involving working should be answered with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at; correct answers which do not show working will **not** be awarded full marks.

Questions containing the instruction **estimate** may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained.

SECTION C : Comprehension and Interpretation

Marks Allotted: 36 marks out of 180 (20%). Attempt BOTH questions in this section.
Candidates are reminded of the need for clear and concise presentation of answers.
Diagrams (sketches), equations and/or numerical results should be included where appropriate.

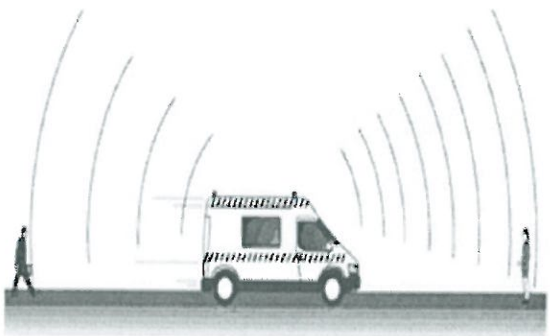
QC1 [18 marks]

Hubble's Law

When a source of waves is moving, a stationary observer notices a change in frequency of the waves. This effect is observed for both longitudinal and transverse waves. For example, if an ambulance moves towards you the sound frequency you hear is higher than the frequency its siren is emitting. This is known as the Doppler Effect.

If a source of electromagnetic waves, such as a star, is travelling away from an observer then the wavelengths of the lines in its electromagnetic spectrum are shifted to higher values. This is called red shift. An equation for the relationship is as follows:

$$z = \frac{\Delta\lambda}{\lambda}$$ It can also be shown that: $$z = \frac{v}{c_0}$$

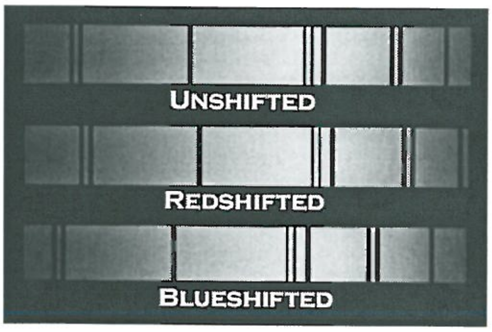


z = red shift
$\Delta\lambda$ = change in wavelength (moving source) (nm)
λ = wavelength of stationery source (nm)
v = recessional speed of galaxy (m s^{-1})
c_0 = speed of light in a vacuum (m s^{-1})

Edwin Hubble analysed the red shifts of various galaxies in 1920 and deduced that most galaxies are moving away from the Earth, this suggests that the Universe is expanding. Hubble also discovered that the further away a galaxy is, the bigger its red shift and the faster it is moving away. This relationship is known as Hubble's Law and can be stated algebraically as follows:

$$v_{galaxy} = H_0 . d$$

v_{galaxy} = recessional speed of galaxy (km s^{-1})
d = distance to galaxy (Mpc)
H_0 = Hubble's constant (km s^{-1} Mpc^{-1})



The distances to galaxies can be estimated by observing Cepheid Variables within a galaxy. A Cepheid Variable is a class of star that pulsates. The relationship between the period of pulsation and the size of the star is very precise. An understanding of how brightness diminishes with distance allows astronomers to estimate distances to galaxies with a high degree of confidence.

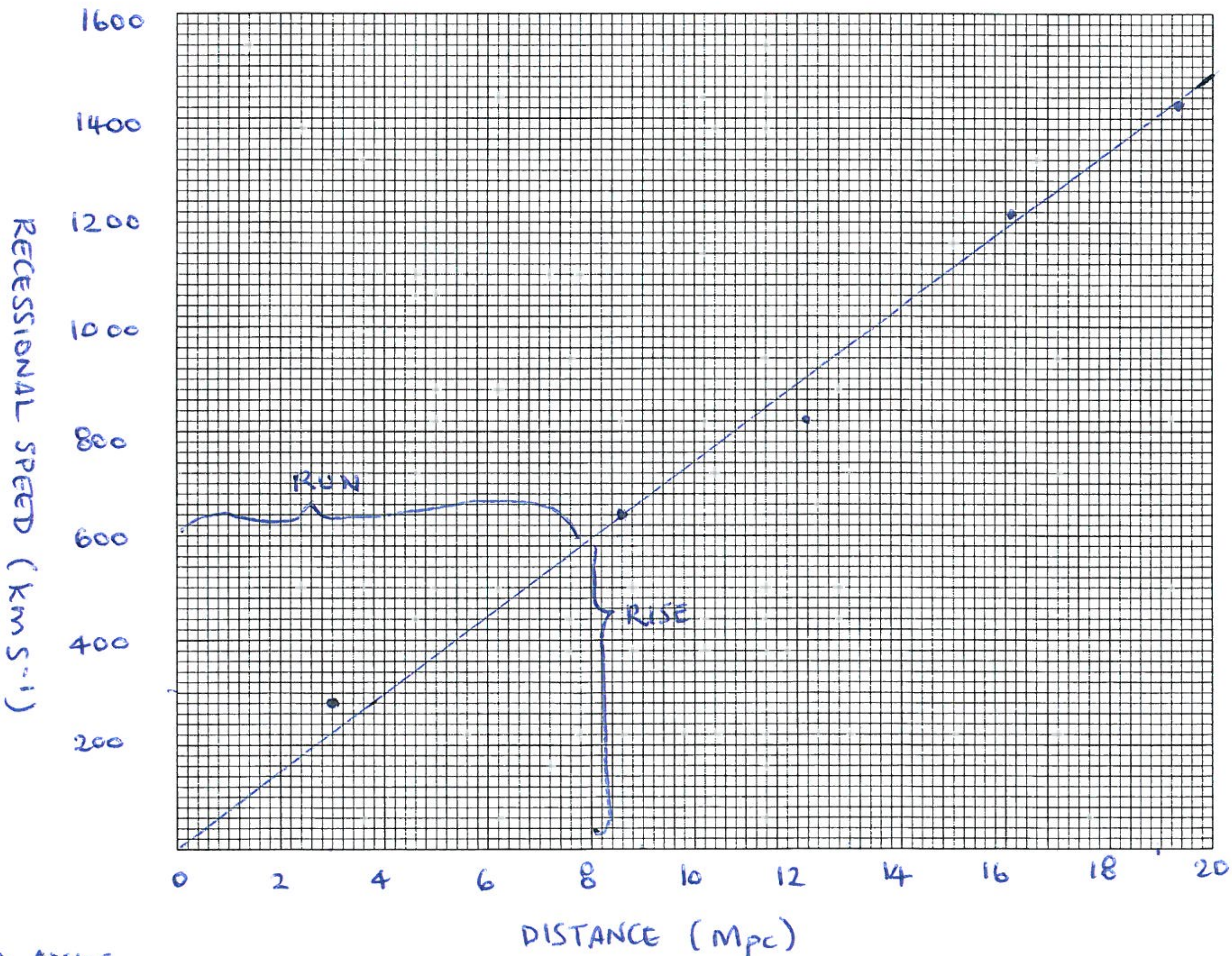
The following data was recorded by the Hubble Space Telescope for five galaxies.

Distance (Mpc)	**Red shift - z**	**Recessional speed of galaxy** v_{galaxy} (km s^{-1})
3.1	0.00095	285
8.6	0.00212	636
12.2	0.00273	819
16.1	0.00402	1206
19.4	0.00473	1419

QUESTIONS:

1a) Calculate the appropriate values in the final column of the table (the first value has been done for you) [2 marks]

2b) Plot a correctly labelled graph of recessional speed versus distance to galaxy on the graph paper and draw a line of best fit.



- AXES
- LABELS /UNITS
- PLOTTING
- LOBF

[4 marks]

1c) Calculate a value for Hubble's constant, in the correct units, clearly showing how you obtained this value from your graph.

✓ IDENTIFIES RISE AND RUN ON LINE OF BEST FIT (NOT DATA POINTS)

H_0 = GRADIENT = RISE / RUN

$= \frac{1480-0}{20-0}$ ALTERNATIVELY: $\frac{600-0}{8-0}$

$= 74\ km\ s^{-1}\ Mpc^{-1}$ $\simeq 75\ km s^{-1}\ Mpc^{-1}$

(RANGE ACCEPT $70 < H_0 < 76$)

[3 marks]

1d) State three reasons why you think that measurements of Hubble's constant have varied widely since Hubble's first determination in 1920.

- IMPROVED TECHNOLOGY TO MEASURE RED-SHIFT (DIFFRACTION GRATINGS)
- BETTER TELESCOPES (EG HUBBLE AND OTHERS LOCATED ABOVE ATMOSPH
- MORE CEPHEID VARIABLES DISCOVERED — BETTER AVERAGE MEASURE

[3 marks]

1e) Explain why the values of red shift, z, have no units.

SAME UNITS IN TOP / BOTTOM OF QUOTIENT
SO IT IS A RATIO OF LENGTH

[1mark]

1f) A line in the spectrum of ionised calcium has a wavelength of 393.3 nm when measured in the laboratory. When similar light from the galaxy NGC 3350 is measured, its wavelength is 394.64 nm. Use the red shift formulae to determine the recessional speed of this galaxy.

SINCE $z = \Delta\lambda / \lambda = V / C_o$

THEN $V = \frac{\Delta\lambda \times C_o}{\lambda}$

$= \frac{((394.64 - 393.3) \times 3 \times 10^8)}{393.3}$

$= 1.02 \times 10^6 \; ms^{-1}$

$= 1.02 \times 10^3 \; kms^{-1}$

[2marks]

1g) For the recessional speed you calculated in part f), use your graph and line of best fit to determine the distance to this galaxy in Mpc.

FROM THE GRAPH IT IS APPROXIMATELY 14 Mpc

(SAY 13.5 Mpc FOR MY GRAPH)

[1mark]

1h) Determine how many years it takes for light from galaxy NGC 3350 to reach Earth. (1 parsec = 3.26 ly)

USING 13.5 Mpc $= 13.5 \times 10^6 \times 3.26$

$= 44.0$ MILLION LIGHT YEARS

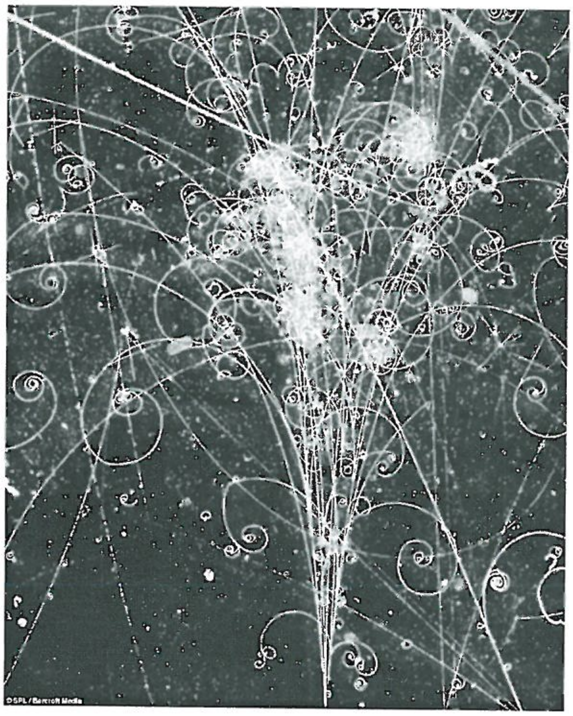
SO IT TAKES APPROXIMATELY 44 MILLION YEARS TO REACH EARTH

ACCEPT RANGE OF 42 – 46 MILLION YEARS

[2marks]

QC2 [18 marks]

Particle Physics – basic principles and techniques



Particle physics is the modern version of the age old quest – to find the smallest particles that cannot be broken down. Particle accelerators are the 'laboratory equipment' in this area of study.

Charged particles can be accelerated in two senses – by their change of direction in circular paths or by increasing their speed. Studies can be made on the radiation that they emit whilst being accelerated or the after effects of collisions between high speed particles.

The cyclotron first came into use in 1928 using a combination of magnetic and electric fields to accelerate particles in a spiral path. Development of this technology led to the synchrotron which uses an evacuated circular tube with many magnets placed around its circumference.

As particles are accelerated the electric field is adjusted and the strength of the magnets is increased to maintain a constant radius and compensate for relativistic effects that become important at high particle energies.

Any charged particle that accelerates will radiate electromagnetic energy. This is true even at a constant speed in a circular path. So a continual supply of energy is required in synchrotrons to just maintain a constant particle speed let alone increase their speed. The emitted radiation is known as synchrotron radiation and can cover the entire electromagnetic spectrum.

Linear accelerators (LINAC) use a straight path and a series of accelerating voltages as the particles move along the line. LINACs are often used to provide the early stages of acceleration before particles are fed into large synchrotrons.

Collider experiments take two beams of particles that have been separately accelerated in opposite directions and smash them into each other. This is difficult to achieve but if successful it is an efficient use of energy.

When two particles with an equal magnitude of momentum collide head on, the total momentum is zero before and after the collision. If particles are stationary after the collision then their kinetic energy is zero. By the conservation of energy and mass principle, the energy before the collision is transformed into the mass of new particles formed in the collision. The particles that are present after a collision reaction can be different to those that went in. This is exactly what particle physicists aim to achieve and the discovery and study of these new particles underpins their work.

Every collision is governed by one of the fundamental forces (except the force of gravity which has no significant influence on such tiny particles in this context):

- The **electromagnetic force** leads to simple collisions between charged particles. No new particles are formed when this force is at work.
  e.g. $p + p \rightarrow p + p$

- The **strong force** dominates reactions between hadrons (which contain quarks).
  e.g. $p + p \rightarrow p + n + \pi^0$

- The **weak force** is likely to be involved in lepton reactions, especially if one of the leptons is a neutrino. e.g. $\nu_e + \mu^- \rightarrow e^- + \nu_\mu$

Einstein's theory of **special relativity** has led us to the idea that the mass of a moving object is not the same as its rest mass (m_0). The mass of a moving object cannot be measured directly; it must be calculated from a measurement of momentum and velocity. The relativistic equations for momentum ***p*** and total energy ***E*** are as follows:

$$p = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad E = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

(These equations are only applicable for non-zero mass)

Relativity has also given us the idea of mass-energy equivalence. In Newton's version of mechanics a lone particle not influenced by gravity or electromagnetism but moving at a given speed could only have a single form of energy – kinetic. At rest it had no energy at all. This is not the case in relativity.

The relationship is described by the equation: $E^2 - p^2c^2 = m_0{}^2c^4$

Photons are packets of energy travelling at the speed of light.

Surprisingly it has been proved that although photons have zero mass they do have momentum.

It can be shown for a photon that if: $E^2 - p^2c^2 = m_0{}^2c^4$ then: $p = \frac{E}{c}$

and since $E = hf$ then: $p = \frac{hf}{c} = \frac{h}{\lambda}$

Particle physics has also proven to be vital in understanding the nature of the universe a few fractions of a second after the Big Bang. The conditions created in the mightiest accelerators are very similar to those that existed when the universe was 10^{-12} seconds old.

Questions

2a) In what sense can a particle be accelerated if its speed remains constant? Explain.

VELOCITY HAS MAGNITUDE AND DIRECTION (VECTOR)

IF A PARTICLE UNDERGOES CIRCULAR MOTION, A CHANGE IN DIRECTION IS ALSO AN ACCELERATION.

[2 marks]

2b) Once a charged particle has been accelerated to a given speed in a circular path, is further energy required to maintain a constant speed? Explain.

YES IT RADIATES SYNCHROTRON RADIATION SO THIS ENERGY (LOSS) MUST BE REPLACED

[2 marks]

2c) Can electrons and neutrinos be subject to the strong force? Explain

NO THE STRONG (NUCLEAR) FORCE ONLY ACTS BETWEEN HADRONS / NUCLEONS / QUARKS

(ELECTRONS AND NEUTRINOS ARE LEPTONS)

[2 marks]

2d) If neutrinos are involved in a collision reaction why is it unlikely that this was governed by the electromagnetic force?

NEUTRINOS HAVE NO CHARGE SO THEY HAVE NO MAGNETIC OR ELECTRIC FIELDS AND SO ARE NOT INFLUENCED BY ELECTROMAGNETIC FORCE.

[1 mark]

2e) If you hit a ping pong ball with a table tennis bat which of the three fundamental forces described governs this collision? Justify your answer.

THE ELECTROMAGNETIC FORCE BECAUSE THE STRONG FORCE ACTS WITHIN A NUCLEUS; THE WEAK FORCE IS INVOLVED WITH BETA DECAY.

INVOLVES THE INTERACTION BETWEEN LIKE CHARGES WITHIN THE BAT AND THE BALL

[2 marks]

2f) Calculate the momentum of a proton travelling at 95% of the speed of light. The rest mass of a proton is given in the formula and constant sheet.

USING $p = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}}$

$= \frac{1.67 \times 10^{-27} \times 0.95 \times 3 \times 10^8}{\sqrt{1-\frac{0.95^2}{1^2}}}$

$= 1.524 \times 10^{-18}$ kg m s^{-1}

[3 marks]

2g) The equation for Einstein's mass-energy equivalence is: $E^2 - p^2c^2 = m_0^{\ 2}c^4$

Show that for a particle at rest this simplifies to $E = m_0 c^2$

IF $v = 0$ THEN $p = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}} = 0$ (NON ZERO MASS)

SO $E^2 - p^2c^2 = m_0^2 c^4$

SO $\sqrt{LHS} = \sqrt{RHS}$

$\therefore \sqrt{E^2 - 0^2c^2} = \sqrt{m_0^2 c^4}$

$\therefore \quad E = m_0 c^2$

[2 marks]

2h) From the starting point: $E^2 - p^2c^2 = m_0^{\ 2}c^4$

show that the momentum of a **photon** with zero mass can be given by $p = \dfrac{E}{c}$

IF $E^2 - p^2c^2 = m_0^2c^4$ AND $m_0 = 0$

THEN $E^2 - p^2c^2 = 0$

THEN $E^2 = p^2c^2$ AND $p^2 = \frac{E^2}{c^2}$

$\therefore \quad p = \frac{E}{c}$ ($\sqrt{}$ BOTH SIDES)

A PHOTON HAS ZERO MASS !

[2 marks]

2i) Calculate the momentum of a photon of 550 nm yellow light.

USING $p = h/\lambda$

THEN $p = \frac{6.63 \times 10^{-34}}{550 \times 10^{-9}}$

$\therefore \quad p = 1.205 \times 10^{-27}$ kg ms^{-1}

[2 marks]