OCR A-Level Physics: Practice Paper 4

Focus: Problem Solving, Application to Unfamiliar Contexts

Difficulty: Hard

Time: 2 hours 15 minutes

Marks:

Section A (multiple choice): 20 marks (30 minutes)

Section B (standard questions): 80 marks (1 hour 45 minutes)

Grade Boundaries: (approximate)

A*: 80 (80%)

A: 70 (70%)

B: 60 (60%)

C: 50 (50%)

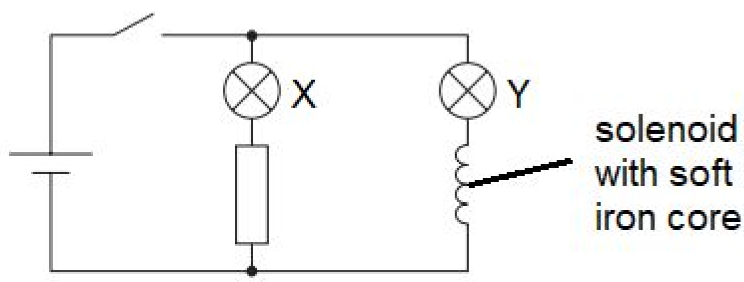
D: 40 (40%)

Advice:

1. Read the questions carefully - look out for tricks.
2. Some questions are harder than the A-level standard.
3. Apply existing knowledge to unfamiliar questions.
4. Check the fully worked solutions for any questions you missed.

Section A: multiple choice. You are advised to spend no more than **30 minutes** in Section A.

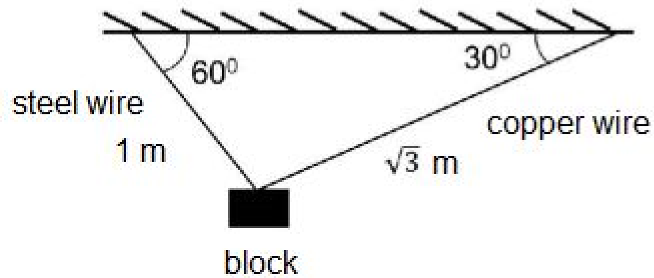
1. A circuit is set up as shown in the diagram. Lamps X and Y are identical, with X in series with a fixed resistor of resistance R and with Y in series with a solenoid whose resistance is also R. The coil in the solenoid has a soft iron core.



The switch is closed and lamp X lights instantly. By considering the magnetic field produced in the solenoid, which of these best describes the behaviour of lamp Y?

O Lights after a delay with a final brightness less than X
O Lights after a delay with a final brightness the same as X
O Lights instantly with less brightness than X
O Lights instantly with the same brightness as X [2 marks]

2. A block of weight 100 N is suspended by copper and steel wires of same cross sectional area 0.5 cm^2 and, length $\sqrt{3}$ m and 1 m, respectively. Their other ends are fixed on a ceiling as shown in figure. The angles subtended by copper and steel wires with the ceiling are 30^o and 60^o respectively.



Given that the ratio of the Young modulus of steel to the Young modulus of copper is 2 : 1, what is the ratio of the extension of the copper wire to the extension of the steel wire?

O 1 : 2
O 2 : 1
O $\sqrt{2}$: 1
O 4 : 1 [2 marks]

3. A particular material obeys Hooke's law in its elastic region. The area below the stress-strain curve for this material in its elastic region represents the

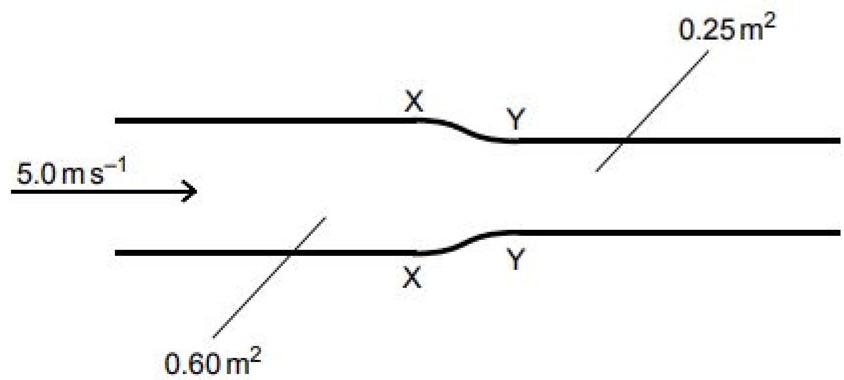
O Young modulus of the material
O Elastic potential energy stored per unit volume of material
O Extension per unit cross-sectional area of material
O Energy lost to the surroundings as heat [2 marks]

4. An atomic nucleus of mass *m* is struck at rest directly by a neutron of mass *m*/240 and speed *u*. The neutron and the nucleus coalesce and move at a collective speed *v*.

The value of *u*/*v* is

O 240
O 241
O 57600
O 57840 [2 marks]

5. Oil of density 800 kg m^{-3} is pumped through a pipe of circular cross-sectional area 0.60 m^2 at a speed of 5.0 ms^{-1}.

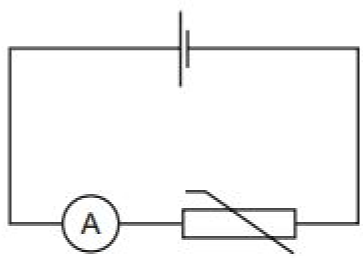


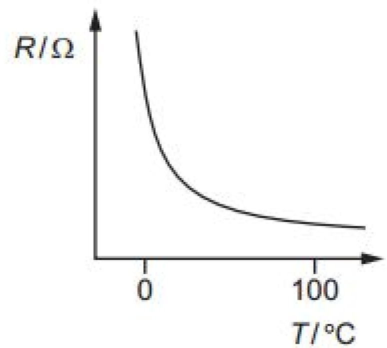
Between points X and Y, the pipe's cross-sectional area decreases to 0.25 m^2. What is the resultant force exerted on the oil as it passes from X to Y?

[2 marks]

6. An analogue ammeter is to be recalibrated as a thermometer by connecting to a circuit in series with a cell of negligible internal resistance and an NTC thermistor.

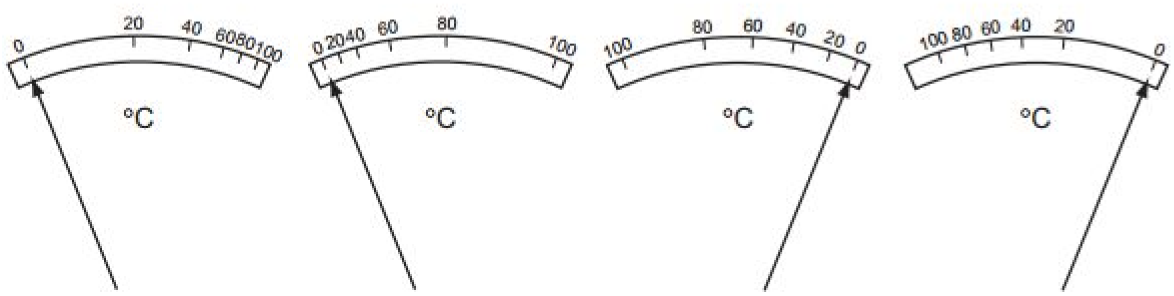
The circuit is shown on the left and the variation of temperature with the resistance of the thermistor is shown on the right.





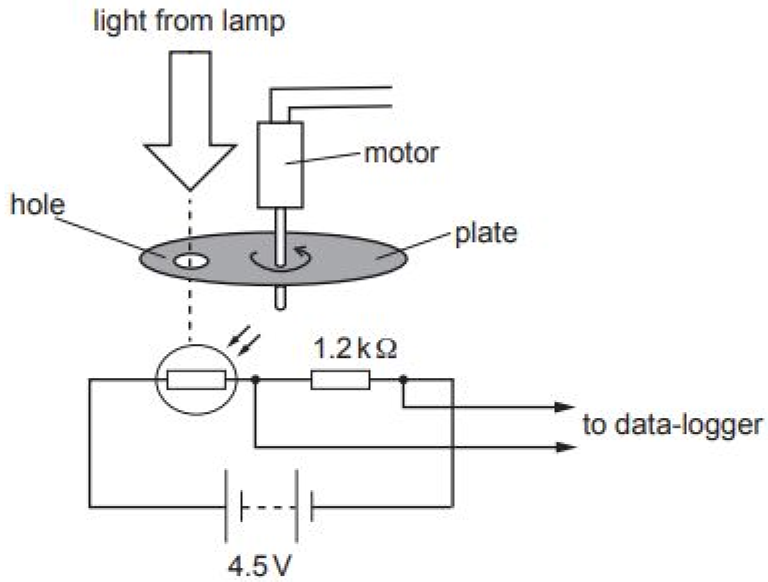
Which diagram could represent the temperature scale on the ammeter?

A **B** **C** **D**

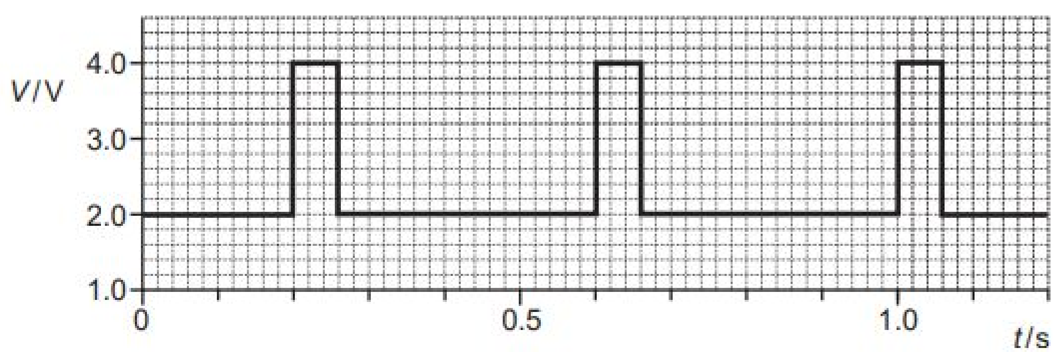


O **A**
O **B**
O **C**
O **D** [2 marks]

7. A metal circular plate is rotated at a constant frequency by an electric motor. The plate has a small hole close to its rim which is exposed to light from a lamp.



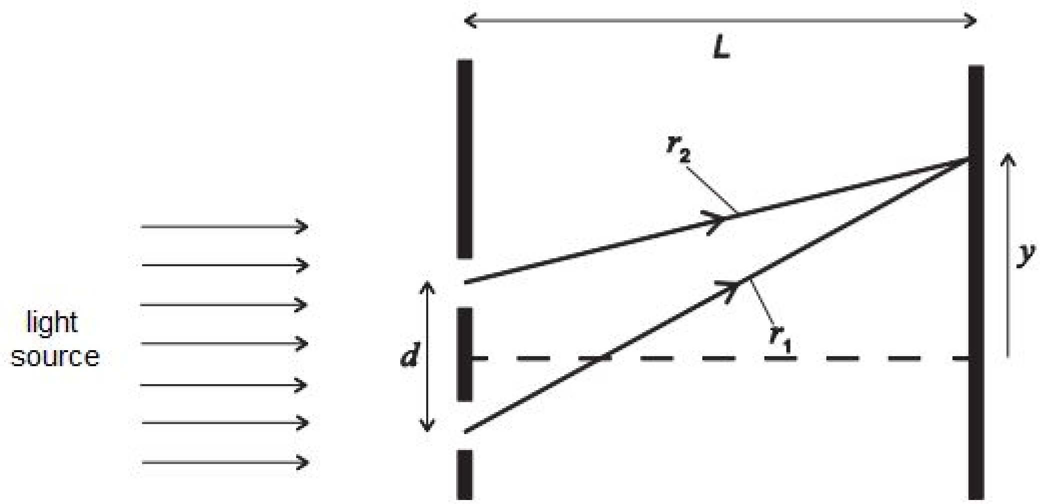
A light-dependent resistor (LDR) and a fixed resistor of resistance 1.2 kΩ are connected in series to a battery. The battery has e.m.f. 4.5 V and has negligible internal resistance. The potential difference *V* across the resistor is monitored using a data-logger. The graph shows the variation of *V* with time *t*.



What is the difference between the resistances of the LDR when it is exposed to the light of the lamp and when it is covered by the rotating plate?

O 450 Ω
O 900 Ω
O 1350 Ω
O 1800 Ω [2 marks]

8. The diagram shows the geometry for two slit diffraction of light, with the slits on the left and the viewing screen on the right, with slit separation *d* and distance *L* such that *d* << *L*;



The pair of slits is illuminated by coherent laser light of wavelength λ = 600 nm. A diffraction pattern appears on the viewing screen.

A thin piece of transparent material, thickness 300 nm and in which the speed of light is half that in air, is now placed immediately behind **one** of the two slits.

What happens to the diffraction pattern and why?

O The diffraction pattern is unchanged because the light is still coherent.

O The diffraction pattern disappears because the light from the two slits is no longer in phase.

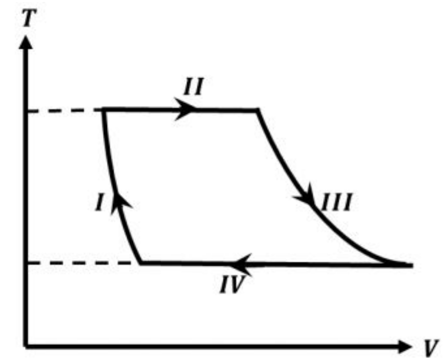
O The complete diffraction pattern shifts in the *y*-direction because the path difference required for a maxima to appear has changed.

O Each maximum is replaced by two because the material halves the wavelength of the light coming from it.

[2 marks]

9. One mole of a monatomic ideal gas undergoes a cyclic sequence of thermodynamic processes as shown in the diagram (where *V* is the volume occupied and *T* is the temperature).

The processes are labelled **I**, **II**, **III** and **IV** below.



Which of these statements are true?

1 Processes **I** and **III** occur at constant (but different) pressures
2 In Process **II**, the gas absorbs heat energy
3 In Process **IV**, the work done on the gas by the surroundings equals the heat energy released by the gas

O **1** and **2** only
O **1** and **3** only
O **2** and **3** only
O **1**, **2** and **3** [2 marks]

10. A person twirls a circular ring (of mass M and radius R) near the tip of their finger as shown in Figure 1. In the process the finger never loses contact with the inner rim of the ring. The finger traces out the surface of a cone, shown by the dotted line. The radius of the path traced out by the point where the ring and the finger is in contact is r. The finger rotates with an angular velocity ω_0.

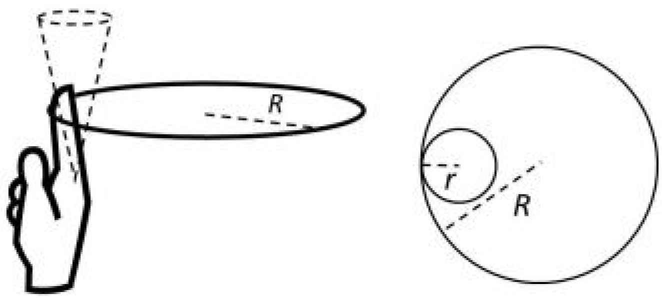


Figure 1 Figure 2

The rotating ring rolls without slipping on the outside of a smaller circle described by the point where the ring and the finger is in contact (Figure 2).

The kinetic energy of the ring is

O $1/2\ M\omega_0^2R^2$

O $1/2\ M\omega_0^2r^2$

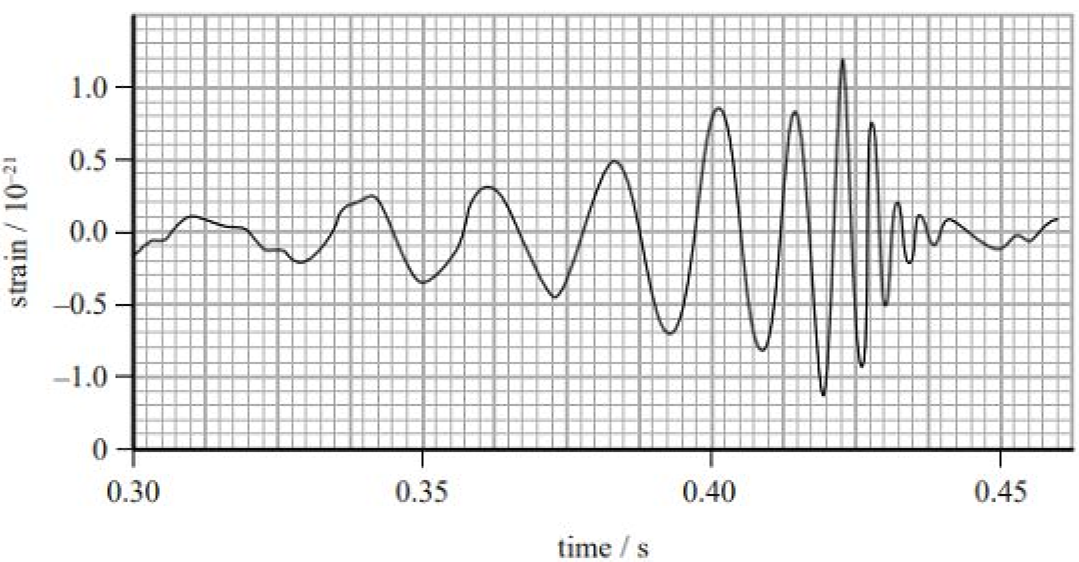
O $1/2\ M\omega_0^2(R - r)^2$

O $1/2\ M\omega_0^2(R^2 - r^2)$ [2 marks]

Section B: standard questions. You are advised to spend **most** of your time in Section B.

11. In 2016, scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced that gravitational waves had been detected.

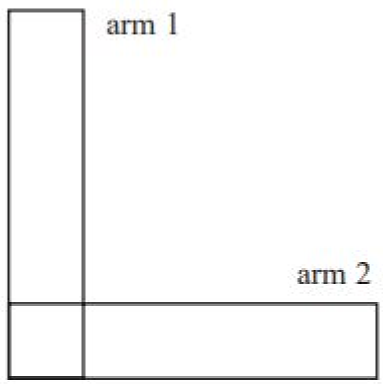
The signal they detected is shown on the graph.



a. Gravitational waves propagate at the speed of light.

Estimate the mean wavelength of the waves detected between 0.30 s and 0.35s on the graph. [3 marks]

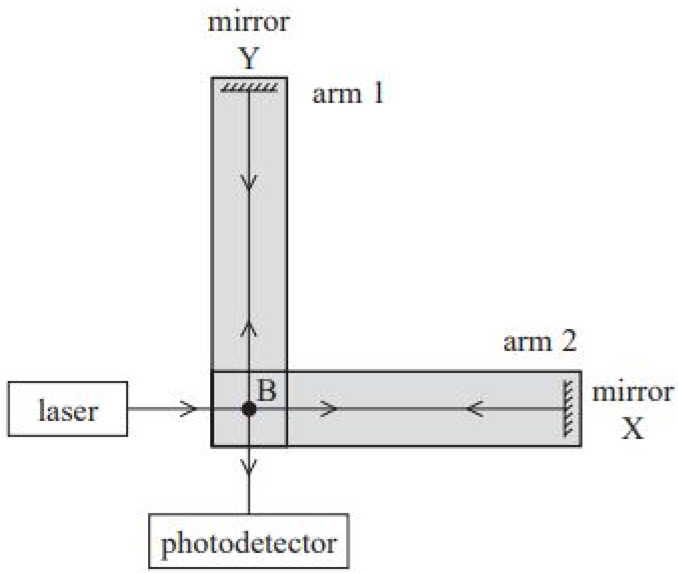
b. Gravitational waves alternately compress and stretch matter by very small amounts as they pass through. The LIGO detector has two arms, at 90° to each other, each 4 km long. As a gravitational wave passes the detector, the arms change length. The detector continuously compares the lengths of the two arms.



i) An article states that ‘the maximum change in the 4 km length of the arm is about 0.001 times the diameter of a proton’.

Determine whether this statement applies to the gravitational wave shown in the graph. [3 marks]

ii) In the LIGO detector, any change in the lengths of the arms is detected using a laser beam and photodetector.



The laser beam is split into two at B, one beam travelling to one mirror and the other beam travelling to the other mirror. After reflection at the mirrors, the beams are recombined at B and reach the photodetector. The photodetector measures the intensity of the incident light.

The system is arranged so that when no gravitational waves are present, the beams have a path difference of half a wavelength at the photodetector.

Explain how the photodetector detects very small changes in the length of one arm, when the other arm stays the same length. [4 marks]

iii) The system could be arranged so that when no gravitational waves are present, the beams have zero path difference at the photodetector.

Explain whether using an initial path difference of half a wavelength is a more sensitive way of detecting changes in length than having an initial path difference of zero. [2 marks]

c. The quantum unit of gravitational waves is thought to be a hypothetical particle known as the *graviton*, just as the quantum unit of electromagnetic waves is the photon. As of 2020, gravitons have not been detected.

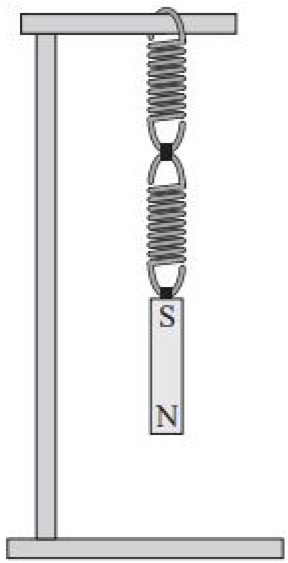
i) Assuming gravitons exist, suggest why gravitons are difficult to detect. [2 marks]

ii) Gravitational lensing is the effect of light arriving from distant celestial objects being distorted by the gravitational influence of mass between the observer and the object. This implies that photons interact with the gravitational force.

Suggest why photons are affected by gravity despite having no mass. [1 mark]

[Total for Q11: 15 marks]

12. Two identical springs are joined in series and a bar magnet is hung from one end as shown.



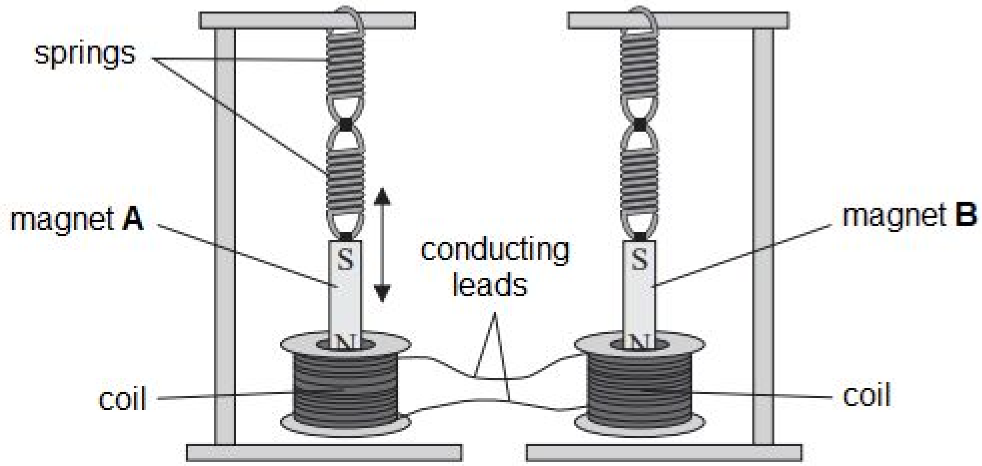
The bar magnet is displaced a small distance vertically from its equilibrium position and released.

a. Calculate the frequency at which the system oscillates.

(Given: mass of magnet = 120 g, spring constant of each spring = 22 Nm^{-1}. Assume negligible interaction between the magnet and the spring/stand.)

[4 marks]

b. The setup is duplicated with identical bar magnets now being suspended from identical springs, with the North pole of each magnet inside a coil of wire as shown. The two coils are connected together with conducting leads.



Magnet A is displaced so that it oscillates vertically. The North pole of magnet A moves into and out of the coil of wire with simple harmonic motion. As this motion continues, magnet B starts to oscillate.

i) Explain why the amplitude of magnet B's oscillations increases over time and predict what will happen to magnet A. [7 marks]

ii) The system is left to oscillate without influence from any external forces.

By considering conservation of energy, explain why the amplitude of the oscillations of magnet B increases up to a value which is less than the initial amplitude of magnet A. [3 marks]

iii) The system is brought to rest. Magnet B is removed and reattached in an inverted position such that its South pole is now facing into the coil. Magnet A remains unchanged. Magnet A is displaced again by the same initial displacement as before.

Predict **one** way in which the long-term behaviour of this system differs to the case where both magnets had their North poles facing into the coils.

[1 mark]

[Total for Q12: 15 marks]

13. A grenade explodes on the surface of horizontal ground. Several fragments and dirt particles are scattered in all directions with varying velocities.

a. Show that the projectile particles with initial speed v ms^{-1} landing a distance r m from the centre of explosion will do so at times t s after the explosion related by the equation

$$\frac{1}{2}g^2t^2 = v^2 \pm \sqrt{v^4 - g^2r^2}$$

.

You may assume no air resistance and may also ignore the motion of particles directly into the ground. [10 marks]

Space for working continues on the next page.

b. The equation of motion derived in part a) contains a ± sign. This indicates two possible times of flight for a projectile with a given initial speed and distance travelled.

Suggest how the paths of two particles with the same initial speed and landing at the same distance from the centre of the explosion may differ in order for them to have different times of flight. [2 marks]

[Total for Q13: 12 marks]

14. Understanding of the interaction of electromagnetic radiation with matter was radically changed by experiments conducted in the early 20th century. After Einstein's wave theory of light was able to explain the photoelectric effect, further confirmation of the wave nature of light came from an experiment on X-rays conducted by Arthur Compton in 1923.

The Compton effect is a form of inelastic scattering, due to the interaction of X-rays with an electron. For X-rays with energies in the range 0.5-5 MeV, the X-ray is scattered with a longer wavelength. It was observed that the increase in wavelength, $\Delta\lambda$, depended only on the angle by which the X-ray was deflected.

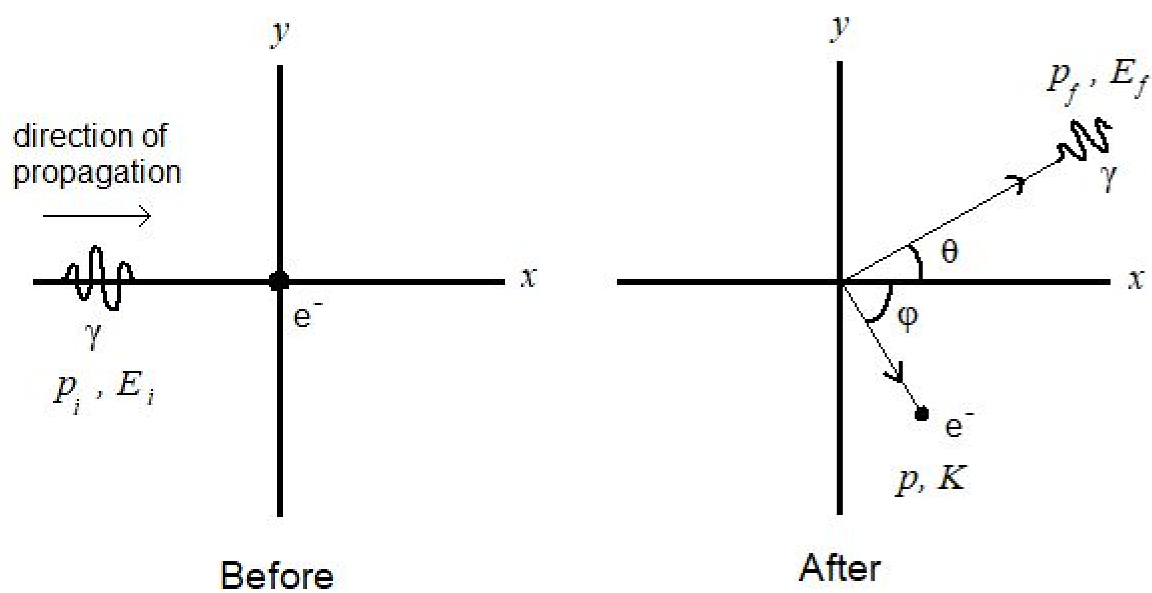
a. i) In terms of the momentum and energy transfers involved, state what is meant by an inelastic collision. [2 marks]

ii) Compton's experiment was initially carried out with a beam of X-rays fired at a thin slice of graphite.

State and explain what Compton must have observed from his experiment in order to correctly conclude that the Compton effect is both a one-to-one interaction, and does so with an electron and not the nuclei of the atoms in the graphite. [4 marks]

b. Let us consider a coordinate system in which an X-ray photon of initial momentum p_i and energy E_i propagates along the x-axis and collides with a stationary electron at the origin. Afterwards, the X-ray is scattered with momentum p_f and energy E_f at an angle of θ to the positive x-axis and the electron moves with momentum p and kinetic energy K at an angle of φ to the positive x-axis:

(p, p_i and p_f are scalar values, the magnitude of their respective vector quantities)



i) By considering conservation of momentum, show that the momenta of the electron and photon and the angle of scattering of the X-ray are related by $p_i^2 + p_f^2 - 2p_i p_f \cos\theta = p^2$.

[4 marks]

ii) The relativistic correction to Einstein's mass-energy equivalence formula is given by

$$E^2 = p^2c^2 + m_0^2c^4$$

where E, p and m_0 are the **total** energy, momentum and rest mass of the particle respectively and c is the speed of light.

Using the above relation and another relevant physical principle, show that

$$\frac{K^2}{c^2} + 2Km_e = p^2$$

where m_e is the rest mass of the electron. [3 marks]

iii) Hence, by combining the relations found in part i) and ii), show that the change in wavelength of the photon due to Compton scattering is given by

$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

where h is Planck's constant, and find the value of the **maximum** increase in the wavelength of the X-ray photon, assuming the photons can be scattered through any angle $0^o \leq \theta \leq 180^o$. [7 marks]

[Total for Q14: 20 marks]

15. Consider this model for circular motion in a vertical plane.

A particle P of mass m kg is moving in a circular path of radius r m in a vertical plane. If point **A** is the lowest point on the circle, then v is the linear speed of P at an angular displacement of θ radians clockwise in the plane of viewing from **A**. Let the speed of P at **A** be u ms^{-1}.

a. When particle P is held in its circular path by a taut string and the tension in the string is T N, the motion of P can be analysed by considering forces.

i) Show that, at any time while the string remains taut,

$$T - mg\cos\theta = \frac{mv^2}{r}.$$

You should include a free-body diagram of P to help you. [3 marks]

ii) Explain the significance of the negative sign in front of the $mg\cos\theta$ term in the left-hand side of the above equation. [1 mark]

iii) If no forces other than the tension in the string and the weight act on P, explain whether v is constant throughout the motion.

[2 marks]

iv) By considering the principle of conservation of energy, show that

$$u^2 = v^2 + 2gr(1 - \cos\theta).$$

[3 marks]

b. Three scenarios are described below as **1**, **2** and **3**. Each uses the model for vertical circular motion described in part a). All circles described are in a vertical plane and resistive forces should be neglected unless otherwise stated.

1 P is a ball rolling around the inside of a fixed hollow horizontal cylinder of internal radius r and the normal reaction force exerted on P by the cylinder wall is T N.

2 P is a small spherical bead threaded onto a thin metal circular wire of radius r and the component of the reaction force exerted on P by the wire, towards the centre of the circle, is T N.

3 P is a ball rolling on the outside of a fixed solid hemispherical surface of radius r, **A** is the **highest** point on the hemisphere, and the reaction force exerted on P is T N.

i) Consider scenario **1**. Find an expression in terms of r for the minimum value of u such that the ball does not fall from its circular path.

[4 marks]

ii) Consider scenario **2**. Give one difference between this situation and the model developed in part a), and state what, if any, way in which the validity of the model is affected. [2 marks]

iii) Consider scenario **3**, where P is initially placed at **A** and projected horizontally with a small velocity u and the angular displacement from **A** at any time is θ.

Suppose that the hemisphere is in fact rough. Predict, with justification, the effect of including the frictional force between P and the hemisphere surface on the angle θ at which P loses contact with the hemisphere.

You should model the frictional force as being proportional to the magnitude of the reaction force exerted on P at any time. [3 marks]

[Total for Q15: 18 marks]

End of Questions

Question Sources:

Q1:	Edexcel A-Level Physics Past Paper
Q2:	IIT Advanced Past Paper (Physics)
Q5:	ENGAA Past Paper
Q6:	OCR A-Level Physics Past Paper
Q7:	Edexcel A-Level Physics Past Paper
Q8:	ENGAA Past Paper
Q9, 10:	IIT Advanced Past Paper
Q11, 12:	Edexcel A-Level Physics Past Paper
Q13:	STEP (Further Maths) Past Paper