AQA Examination-style questions

Unit 4: Fields and further mechanics

1 The pile-driver crane in **Figure 1** is used on a construction site to drive a steel girder vertically into the ground. The hammer of the pile-driver is raised and dropped repeatedly onto the upper end of the girder.

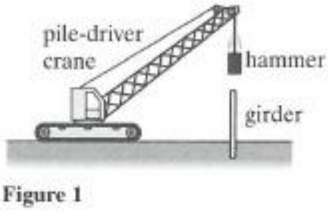

Figure 1

(a) The hammer is a steel cylinder of length 1.50 m and diameter 0.60 m.

(i) Calculate the mass of the cylinder.
density of steel = 7800 kg m^{-3}

(ii) The hammer is released from a height of 0.80 m above the top end of the girder. Calculate the velocity of the hammer just before it hits the girder. *(4 marks)*

(b) (i) The girder has a mass of 1600 kg. Calculate its velocity immediately after the impact, assuming the hammer does not rebound after the impact.

(ii) The impact causes the girder to penetrate 25 mm into the ground. Estimate the average force of friction on the girder during this movement. *(6 marks)*

AQA, 2007

2 In a football match, a player kicks a stationary football of mass 0.44 kg and gives it a speed of 32 m s^{-1}.

(a) (i) Calculate the change of momentum of the football.

(ii) The contact time between the football and the footballer's boot was 9.2 ms. Calculate the average force of impact on the football. *(3 marks)*

(b) A video recording showed that the toe of the boot was moving on a circular arc of radius 0.62 m centred on the knee joint when the football was struck. The force of the impact slowed the boot down from a speed of 24 m s^{-1} to a speed of 15 m s^{-1}.

(i) Calculate the deceleration of the boot along the line of the impact force when it struck the football.

(ii) Calculate the centripetal acceleration of the boot just before impact.

(iii) Discuss briefly the radial force on the knee joint before impact and during the impact. *(4 marks)*

AQA, 2005

3 When the wheels of a car rotate at 6.5 revolutions per second the external rear view mirror vibrates violently. This is because the centre of mass of one of the wheels is not at the centre of the wheel. To correct this, a mass of 0.015 kg is attached to the rim of the wheel 0.25 m from the centre of the wheel as shown in **Figure 2**.

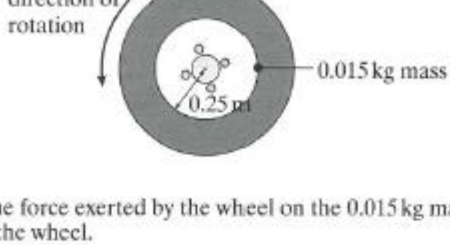

Figure 2

(a) (i) Calculate the force exerted by the wheel on the 0.015 kg mass due to the rotation of the wheel.

(ii) Copy **Figure 2** and draw an arrow to show the direction the 0.015 kg mass would move if it became detached when in the position shown in **Figure 2** while the wheel is rotating. *(4 marks)*

(b) Sketch a graph to show how the vertical component of the force acting on the 0.015 kg mass due to the rotation of the wheel varies with time, t, during one complete rotation of the wheel. At $t = 0$ the 0.015 kg mass is in the position shown in **Figure 2**. Show upwards force as positive and downwards force as negative, and include a suitable time scale. *(2 marks)*

(c) Without the mass in place, the rotation of the wheel makes the external rear-view mirror of the car undergo forced vibrations.

Explain what is meant by *forced vibrations* and state and explain how these vibrations will vary as the car increases in speed from rest. *(7 marks)*

AQA 2004

4 The rotor of a model helicopter has four blades. Each of the blades is 0.55 m long with a uniform cross-sectional area of $3.5 \times 10^{-4}\,m^2$ and negligible mass. An end-cap of mass 1.5 kg is attached to the outer end of each blade.

(a) (i) Show that there is a force of about 7 kN acting on each end-cap when the blades rotate at 15 revolutions per second.

(ii) State the direction in which the force acts on the end-cap.

(iii) Show that this force leads to a longitudinal stress in the blade of about 20 MPa.

(iv) Calculate the change in length of the blade as a result of its rotation.

Young modulus of the blade material = 6.0×10^{10} Pa

(v) Calculate the total strain energy stored in **one** of the blades due to its extension. *(10 marks)*

(b) The model helicopter can be made to hover above a point on the ground by directing the air from the rotors vertically downwards at speed v.

(i) Show that the change in momentum of the air each second is $A\rho v^2$, where A is the area swept out by the blades in one revolution and ρ is the density of air.

(ii) The model helicopter has a weight of 900 N. Calculate the speed of the air downwards when the helicopter has no vertical motion.

Density of air = $1.3\,kg\,m^{-3}$ *(5 marks)*

AQA 2003

5 When the pump of a central heating system reaches a certain speed after being switched on, a straight section of a pipe vibrates strongly.

(a) Explain why the pipe vibrates strongly at a certain pump speed.

(b) State and explain **one** way to reduce these vibrations of the pipe. *(5 marks)*

AQA 2006

6 The International Space Station (ISS) moves in a circular orbit around the Earth at a speed of $7.68\,km\,s^{-1}$ and at a height of 380 km above the Earth's surface.

(a) Calculate the centripetal acceleration of the ISS. *(3 marks)*

(b) Explain why a scientist working on board the ISS experiences 'apparent weightlessness'. *(2 marks)*

This state of apparent weightlessness makes the space station an ideal laboratory for experiments in 'zero gravity', conditions such as the study of lattice vibrations in solids.

(c) **Figure 3** shows a mass–spring system which, in zero gravity, provides a good model of forces acting on an atom in a solid lattice.

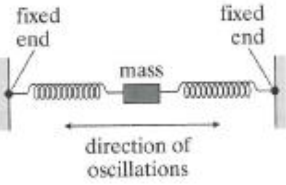

Figure 3

When the mass is displaced and released it oscillates as shown. The motion is very similar to the motion in one dimension of an atom in a crystalline solid. The springs behave like the bonds between adjacent atoms.

(i) The mass in the model system is 2.0 kg and it oscillates with a period of 1.2 s. Show that the stiffness of the spring system is about $55\,N\,m^{-1}$.

(ii) The bonds between the atoms in a particular solid have the same stiffness as the model system and the mass of the oscillating atom is 4.7×10^{-26} kg. Calculate the frequency of oscillation of the atom. *(4 marks)*

AQA 2005

7 **Figure 4** shows a way to measure the mass of a lorry. The vehicle and its contents are driven onto a platform mounted on a spring. The platform is then made to oscillate vertically and the mass is found from a measurement of the natural frequency of oscillation.

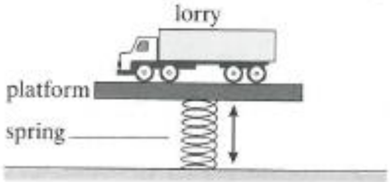

Figure 4

(a) (i) State whether the period of oscillation increases, decreases or remains unchanged when the amplitude of oscillation of the platform is reduced.

(ii) The spring constant k of the supporting spring is increased to four times its original value.

State the value of the ratio

$$\frac{\text{new oscillation period}}{\text{old oscillation period}}$$

(iii) The time period of oscillation is T when a lorry is on the platform. The spring constant of the spring is k. Show that the total mass M of lorry and platform is given by

$$M = \frac{kT^2}{4\pi^2}$$

(iv) A lorry and its contents have a total mass of 5300 kg. The spring constant of the supporting spring k is $1.9 \times 10^5\,N\,m^{-1}$. The frequency of oscillation of the platform with the lorry resting on it is 0.91 Hz.

Calculate the mass of the platform. *(7 marks)*

(b) The driver is required to turn off the vehicle engine whilst the measurement is taking place.

The driver of the lorry in part (a)(iv) fails to do this and slowly increases the frequency of vibration of his vehicle from 0.5 Hz to about 4 Hz whilst the measurement is in progress and the platform is free to move. Describe and explain how the amplitude and frequency of the platform vary as this frequency increase occurs. You should use a sketch graph to support your answer. *(4 marks)*

AQA 2003

8 Whilst investigating the oscillations of a helical spring, a student carried out measurements when various masses were suspended from the spring. For each mass, the length l of the spring was measured and 50 vertical oscillations were timed. The results are shown in the table. *(2 marks)*

length l/mm	time for 50 oscillations/s	time period T/s	T^2/s^2
316	12.5	0.25	0.063
333	17.5		
349	22.0		
364	25.5		
381	28.5		
397	31.0		

(a) Copy and complete the table.

(b) (i) Assuming that the spring obeys Hooke's law, show that

$$T^2 = 4\pi^2\frac{(l - l_0)}{g}$$

where l_0 is the length of the unloaded spring and T is the time period of vertical oscillations.

(ii) Plot a graph of T^2 against l.

(iii) Use the graph to determine values for g and l_0. *(9 marks)*

(c) Estimate the value of l which would give a time period of 1.00 s. State and explain **one** reason why the behaviour of the spring may cause your estimated value to be incorrect. *(4 marks)*

AQA 2005

9 (a) (i) State **one** similarity of electric and gravitational fields.

(ii) State **one** difference between electric and gravitational fields. *(2 marks)*

(b) A satellite of mass 165 kg has the radius of its orbit reduced from 4.24×10^7 m to 8.08×10^6 m.

Calculate the change in potential energy of the satellite and state whether it is an increase or a decrease. *(3 marks)*

(c) The orbital change mentioned in part (b) reduces the period of the orbit from 24 hours to 2 hours. State and explain why each of these orbits is useful for information collection or transfer. *(3 marks)*

AQA 2005

10 (a) State the factors that affect the gravitational field strength at the surface of a planet. *(2 marks)*

(b) **Figure 5** shows the variation, called an anomaly, of gravitational field strength at the Earth's surface in a region where there is a large spherical granite rock buried in the Earth's crust.

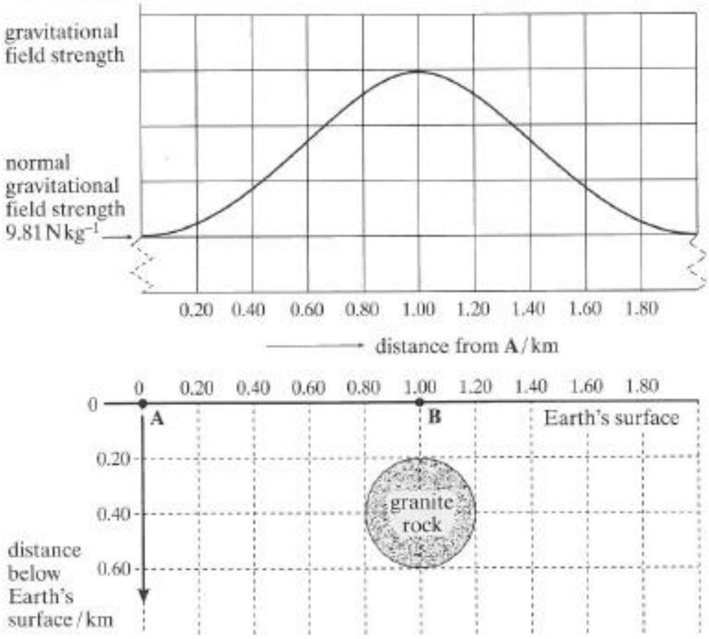

Figure 5

The density of the granite rock is $3700\,kg\,m^{-3}$ and the mean density of the surrounding material is $2200\,kg\,m^{-3}$.

(i) Show that the difference between the mass of the granite rock and the mass of an equivalent volume of the surrounding material is $5.0 \times 10^{10}\,kg$.

(ii) Calculate the difference between the gravitational field strength at B and that at point A on the Earth's surface that is a long way from the granite rock.

(iii) Describe how the graph of gravitational field strength would change if the granite rock were buried deeper in the Earth's crust. *(9 marks)*

AQA 2003

11 A dish on a communications satellite is used to transmit a beam of microwaves of wavelength λ. The beam spreads with an angular width $\frac{\lambda}{d}$, in radians, where d is the diameter of the dish.

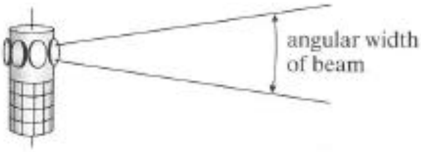

Figure 6

(a) (i) Calculate the angular width, in degrees, of a beam of frequency 1200 MHz transmitted using a dish of diameter 1.8 m.

(ii) Show that the beam has a width of 2100 km at a distance of 15 000 km from the satellite. *(4 marks)*

(b) (i) Show that the speed, v, of a satellite in a circular orbit at height h above the Earth is given by

$$v = \sqrt{\frac{GM}{R + h}}$$

where R is the radius of the Earth and M is the mass of the Earth.

(ii) Calculate the speed and the time period of a satellite at a height of 15 000 km in a circular orbit about the Earth.

(iii) The satellite passes directly over a stationary receiver at the North Pole. Show that the beam moves at a speed of $1.3\,km\,s^{-1}$ across the Earth's surface and that the receiver can remain in contact with the satellite for no more than 27 minutes each orbit. *(9 marks)*

AQA 2005

12 The hydrogen atom may be represented as a central proton with an electron moving in a circular orbit around it as shown in **Figure 7**. When the atom is in the ground state, the radius of the electron's orbit is $5.3 \times 10^{-11}\,m$.

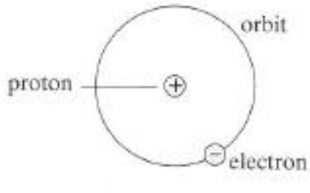

Figure 7

(a) By applying this model to the hydrogen atom in the ground state, calculate:

(i) the force of electrostatic attraction between the electron and the proton,

(ii) the speed of the electron,

(iii) the ratio of the de Broglie wavelength of the electron to the circumference of the orbit. *(6 marks)*

(b) The total energy of the electron in a hydrogen atom may be shown to have discrete values given, in J, by

$$E = \frac{2.2 \times 10^{-18}}{n^2}$$

where $n = 1$ for the ground state, $n = 2$ for the first excited state, and so on.

(i) Calculate the wavelength of the light emitted when the electron returns to the ground state from the first excited state.

(ii) Explain why visible light will not be produced by any transition in which the electron returns to the ground state. *(5 marks)*

AQA 2005

13 (a) An α particle emitted from a certain isotope has a kinetic energy of 2.8 MeV.

(i) Show that the speed of the α particle immediately after it is emitted is $1.2 \times 10^7\,\mathrm{m\,s^{-1}}$.

(ii) Calculate the de Broglie wavelength of the α particle immediately after it is emitted. *(4 marks)*

(b) In a Rutherford scattering experiment, a beam of 2.8 MeV α particles is directed normally at a thin gold foil. An α particle in the beam approaches the nucleus of an atom of the gold isotope head on as shown in **Figure 8**.

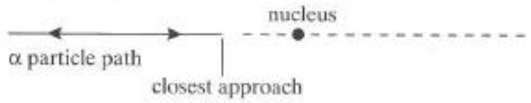

Figure 8

(i) Calculate the least distance of approach of the α particle from the centre of the gold nucleus.

(ii) By comparing your answers to part (a)(ii) and part (b)(i), explain why diffraction of α particles by the gold nuclei is not significant. *(5 marks)*

AQA 2004

14 Two capacitors **A** and **B** are separately charged to a pd of 40.0 V before being discharged through the same resistor of value 10.0 kΩ. The discharge curves are shown in **Figure 9**.

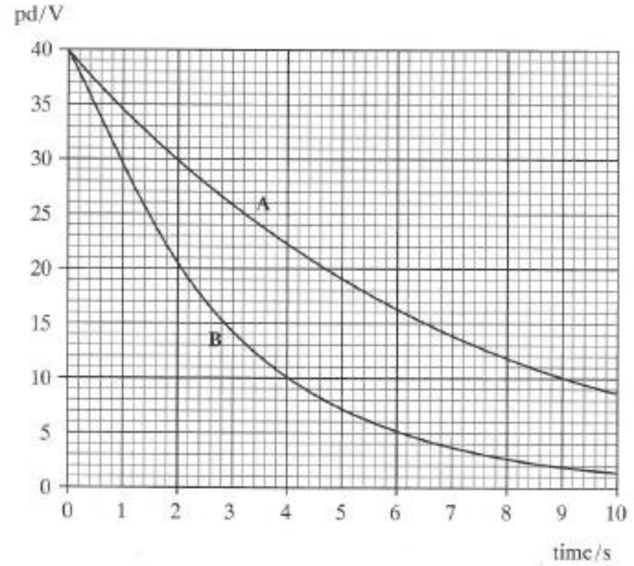

Figure 9

(a) Show that the time for the pd across capacitor **A** to halve is always approximately 4.5 s.

(b) Calculate the capacitance of **A**.

(c) Calculate the energy dissipated in the resistor in the interval between $t = 0$ and $t = 4.0$ s as capacitor **B** discharges. *(8 marks)*

AQA 2007

15 **Figure 10** shows a motor lifting a small mass. The energy required comes from a charged capacitor.

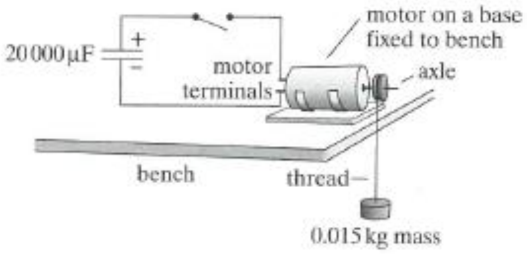

Figure 10

The capacitor was charged to a potential difference of 4.5 V and then discharged through the motor.

(a) (i) The motor only operates when the voltage at its terminals is at least 2.5 V. Calculate the energy delivered to the motor when the potential difference across the capacitor falls from 4.5 V to 2.5 V.

(ii) The motor lifted the mass through a distance of 0.35 m. Calculate the efficiency of the transfer of energy from the capacitor to gravitational potential energy of the mass. Give your answer as a percentage.

(iii) Give **two** reasons why the transfer is inefficient. *(7 marks)*

(b) The motor operated for 1.3 s as the capacitor discharged from 4.5 V to 2.5 V. Calculate:

(i) the average useful power developed in lifting the mass,

(ii) the effective resistance of the motor, assuming that it remained constant. *(5 marks)*

AQA 2004

16 A steel wire of diameter 0.24 mm is stretched between two fixed points 0.71 m apart. A U-shaped magnet is placed at the centre of the wire so that the wire passes between its poles, as shown in **Figure 11**.

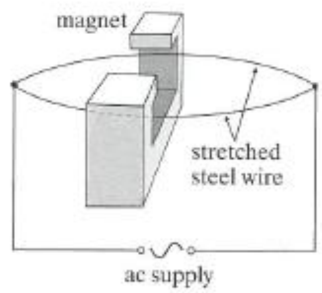

Figure 11

(a) (i) Explain why the wire vibrates when an alternating current is passed through it.

(ii) Explain why the wire vibrates strongly in its fundamental mode when the frequency of the alternating current is 290 Hz.

(iii) Show that the speed of the waves on the wire is 410 m s^{-1}. *(6 marks)*

(b) The speed, c, of waves on a wire of mass per unit length, μ, is related to the tension, T, in the wire by

$$c = \sqrt{\frac{T}{\mu}}$$

(i) The wire in **Figure 11** is at a tension of 60 N. Calculate its mass per unit length.

(ii) Hence calculate the density of the metal. *(5 marks)*

AQA 2005

17 **Figure 12** shows a particle **P** with charge $+6.4 \times 10^{-19}$ C about to enter a region where there is a uniform electric field of strength 2.0×10^{4} N C^{-1}. **Figure 13** shows the same charged particle about to enter a region where there is a uniform magnetic field of flux density 0.17 T directed into the paper.

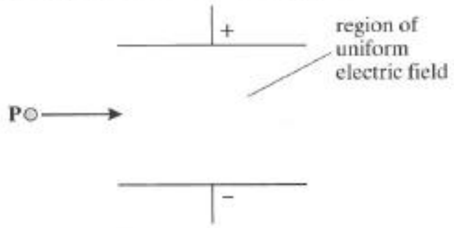

Figure 12

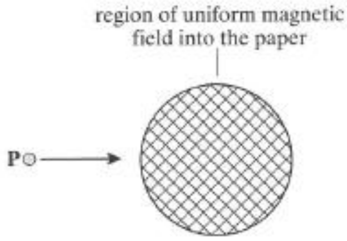

Figure 13

(a) Sketch the paths taken by the particle when in each field. *(2 marks)*

(b) (i) State what is meant by *uniform electric field strength*.

(ii) The separation of the plates in **Figure 12** is 0.045 m. Calculate the potential difference between the plates. *(4 marks)*

(c) (i) Calculate the magnitude of the force on the particle when it is in the electric field.

(ii) Calculate the initial velocity of the charged particle for which the magnitude of the force on the particle is the same in each field. *(4 marks)*

(d) Explain why the speed of the particle changes in one of the above situations but remains constant in the other. *(6 marks)*

AQA 2005

18 (a) A satellite moves in a circular orbit at constant speed. Explain why its speed does not change even though it is acted on by a force. *(3 marks)*

(b) At a certain point along the orbit of a satellite in uniform circular motion, the Earth's magnetic flux density has a component of 56 μT towards the centre of the Earth and a component of 17 μT in a direction perpendicular to the plane of the orbit.

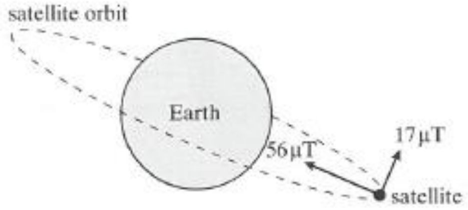

Figure 14

(i) Calculate the magnitude of the resultant magnetic flux density at this point.

(ii) The satellite has an external metal rod pointing towards the centre of the Earth. Calculate the angle between the direction of the resultant magnetic field and the rod.

(iii) Explain why an emf is induced in the rod in this position. *(4 marks)*

AQA 2002

19 In a television cathode ray tube, electrons are accelerated through a potential difference of 12 kV in a vacuum before striking the screen.

(a) (i) Calculate the speed of an electron accelerated through this potential difference.

(ii) The beam current is 25 mA. Calculate the number of electrons that strike the screen in one second. *(4 marks)*

(b) The electron beam is deflected in the television tube by a changing magnetic field produced by currents in coils placed around the tube.

(i) Explain how this changing magnetic field can lead to induction effects in other electrical circuits in the television.

(ii) Explain how this changing magnetic field could lead to faults in these other electrical television circuits.

(iii) The electron beam is moved from the left-hand side of the screen to the right-hand side by uniformly varying the field from -3.5×10^{-4} T to $+3.5 \times 10^{-4}$ T in a time of 50 μs. Each turn of a 250-turn coil of wire in this changing field has an area of 4.0×10^{-3} m^2

Calculate the **maximum** emf that can appear in the 250-turn coil.

(iv) Explain why the answer to part (b)(iii) is a maximum value. *(8 marks)*

AQA 2004

20 (a) Eddy currents in the cores of transformers are one cause of inefficiency in transformers.

(i) Explain what is meant by an eddy current, how eddy currents are produced in transformer cores and why they lead to inefficient operation of the transformer.

(ii) Explain how the design of a transformer minimises the inefficiency due to eddy currents. *(6 marks)*

(b) **Figure 15** shows a laboratory arrangement for demonstrating the operation of a transformer.

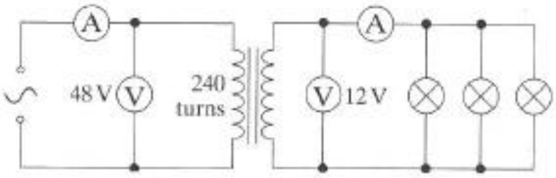

Figure 15

The supply voltage was adjusted until the three 12 V, 36 W lamps operated normally. The voltmeter readings are shown on **Figure 15**. The efficiency of the transformer was 100%.

Calculate:

(i) the reading of the ammeter in the secondary circuit,

(ii) the reading of the ammeter in the primary circuit,

(iii) the number of turns on the secondary coil of the transformer. *(5 marks)*

AQA 2005