This question is in two parts. Part 1 is about kinematics and Newton’s laws of motion.

**Part 2** Electrical circuits

The circuit shown is used to investigate how the power developed by a cell varies when the load resistance \( R \) changes.

The variable resistor is adjusted and a series of current and voltage readings are taken. The graph shows the variation with \( R \) of the power dissipated in the cell and the power dissipated in the variable resistor.

1a. An ammeter and a voltmeter are used to investigate the characteristics of a variable resistor of resistance \( R \). State how the resistance of the ammeter and of the voltmeter compare to \( R \) so that the readings of the instruments are reliable. [2 marks]
1b. Show that the current in the circuit is approximately 0.70 A when \( R = 0.80 \, \Omega \). [3 marks]

1c. The cell has an internal resistance.

Outline what is meant by the internal resistance of a cell. [2 marks]

1d. Determine the internal resistance of the cell. [3 marks]
1e. Calculate the electromotive force (emf) of the cell. [2 marks]
This question is in two parts. **Part 1** is about electrical circuits. **Part 2** is about magnetic fields.

**Part 1 Electrical circuits**

The circuit shown is used to investigate how the power developed by a cell varies when the load resistance $R$ changes.

The variable resistor is adjusted and a series of current and voltage readings are taken. The graph shows the variation with $R$ of the power dissipated in the cell and the power dissipated in the variable resistor.

The cell may be damaged if it dissipates a power greater than 1.2 W. Outline why damage in the cell may occur if the terminals of the cell are short-circuited. [2 marks]
This question is in two parts. Part 1 is about electrical circuits. Part 2 is about magnetic fields.

**Part 2 Magnetic fields**

The diagram shows an arrangement for measuring the force between two parallel sections of the same rigid wire carrying a current as viewed from the front.

Deduce what happens to the reading on the electronic balance when the current is switched on.

When the current in the wire is 0.20 A, the magnetic field strength at the upper section of wire due to the lower section of wire is $1.3 \times 10^{-4}$ T.

Calculate the magnetic force acting per unit length on the upper section of wire.
2d. Each cubic metre of the wire contains approximately $8.5 \times 10^{28}$ free electrons. The diameter of the wire is 2.5 mm and the length of wire within the magnetic field is 0.15 m. Using the force per unit length calculated in (g)(i), deduce the speed of the electrons in the wire when the current is 0.20 A.

2e. The upper section of wire is adjusted to make an angle of 30° with the lower section of wire. Outline how the reading of the balance will change, if at all.
3a. A 24 Ω resistor is made from a conducting wire. 

(i) The diameter of the wire is 0.30 mm and the wire has a resistivity of $1.7 \times 10^{-8}$ Ωm. Calculate the length of the wire.

(ii) On the axes, draw a graph to show how the resistance of the wire in (d)(i) varies with the diameter of the wire when the length is constant. The data point for the diameter of 0.30 mm has already been plotted for you.

3b. The 24 Ω resistor is covered in an insulating material. Explain the reasons for the differences between the electrical properties of the insulating material and the electrical properties of the wire.
An electric circuit consists of a supply connected to a 24Ω resistor in parallel with a variable resistor of resistance \( R \). The supply has an emf of 12V and an internal resistance of 11Ω.

(i) Determine the value of \( R \) for this circuit at which maximum power is delivered to the external circuit.

(ii) Calculate the reading on the voltmeter for the value of \( R \) you determined in (f)(i).

(iii) Calculate the total power dissipated in the circuit when the maximum power is being delivered to the external circuit.
This question is about a thermistor circuit.
The circuit shows a negative temperature coefficient (NTC) thermistor X and a 100 kΩ fixed resistor R connected across a battery.

The battery has an electromotive force (emf) of 12.0 V and negligible internal resistance.

Define electromotive force (emf).
4b. The graph below shows the variation with temperature $T$ of the resistance $R_x$ of the thermistor.

(i) Determine the temperature of X when the potential difference across R is 4.5 V.

(ii) State the range of temperatures for which the change in the resistance of the thermistor is most sensitive to changes in temperature.

(iii) State and explain the effect of a decrease in temperature on the ratio $\frac{\text{voltagexvoltagex}}{\text{voltagexvoltagex}}$.

This question is about the internal resistance of a cell.

5a. Define electromotive force (emf).
A circuit is used to determine the internal resistance and emf of a cell. It consists of the cell, a variable resistor, an ideal ammeter and an ideal voltmeter. The diagram shows part of the circuit with the ammeter and voltmeter missing.

The variable resistor is set to 1.5 Ω. When the cell converts 7.2 mJ of energy, 5.8 mC of charge moves completely around the circuit. The potential difference across the variable resistor is 0.55 V.

5b. Draw on the diagram the positions of the ammeter and voltmeter. [1 mark]

5c. Show that the emf of the cell is 1.25 V. [1 mark]

5d. Determine the internal resistance of the cell. [2 marks]

5e. Calculate the energy dissipated per second in the variable resistor. [2 marks]
This question is in two parts. Part 1 is about energy resources. Part 2 is about electric fields.

Part 2 Electric fields

An isolated metal sphere is placed in a vacuum. The sphere has a negative charge of magnitude 12 nC.

6a. Using the diagram, draw the electric field pattern due to the charged sphere. [2 marks]

Outside the sphere, the electric field strength is equivalent to that of a point negative charge of magnitude 12 nC placed at the centre of the sphere. The radius \( r \) of the sphere is 25 mm.

6b. Show that the magnitude of the electric field strength at the surface of the sphere is about \( 2 \times 10^5 \text{ N C}^{-1} \). [2 marks]

6c. On the axes, draw a graph to show the variation of the electric field strength \( E \) with distance \( d \) from the centre of the sphere. [2 marks]
An electron is initially at rest on the surface of the sphere.

6d. Calculate the initial acceleration of the electron. [2 marks]

6e. Discuss the subsequent motion of the electron. [2 marks]

This question is in two parts. Part 1 is about internal resistance of a cell. Part 2 is about expansion of a gas.

Part 1 Internal resistance of a cell

7a. Outline, with reference to charge carriers, what is meant by the internal resistance of a cell. [3 marks]
The graph shows the voltage–current (V–I) characteristics of a non-ohmic conductor.

The variable resistor in the circuit in (c) is replaced by this non-ohmic conductor.

7b. On the graph, sketch the variation of \( V \) with \( I \) for the cell. [2 marks]

7c. Using the graph, determine the current in the circuit. [3 marks]

This question is in two parts. Part 1 is about electric fields and radioactive decay. Part 2 is about change of phase.

Part 1 Electric fields and radioactive decay

8a. Define electric field strength. [2 marks]

8b. A simple model of the proton is that of a sphere of radius \( 1.0 \times 10^{-15} \text{m} \) with charge concentrated at the centre of the sphere. Estimate the magnitude of the field strength at the surface of the proton. [2 marks]
Protons travelling with a speed of $3.9 \times 10^6 \text{ms}^{-1}$ enter the region between two charged parallel plates $X$ and $Y$. Plate $X$ is positively charged and plate $Y$ is connected to earth.

A uniform magnetic field also exists in the region between the plates. The direction of the field is such that the protons pass between the plates without deflection.

(i) State the direction of the magnetic field.

(ii) The magnitude of the magnetic field strength is $2.3 \times 10^{-4} \text{T}$. Determine the magnitude of the electric field strength between the plates, stating an appropriate unit for your answer.
Outline, with reference to the graph and to Ohm's law, whether or not each component is ohmic. [3 marks]
Components X and Y are connected in parallel. The parallel combination is then connected in series with a variable resistor R and a cell of emf 8.0V and negligible internal resistance.

(i) Using the graph, calculate the resistance of the parallel combination of X and Y.
(ii) Using your answer to (a)(i), determine the resistance of R.
(iii) Determine the power delivered by the cell to the circuit.
10a. Define electric field strength. [2 marks]

10b. The diagram shows a pair of horizontal metal plates. Electrons can be deflected vertically using an electric field between the plates. [5 marks]

(i) Label, on the diagram, the polarity of the metal plates which would cause an electron positioned between the plates to accelerate upwards.

(ii) Draw the shape and direction of the electric field between the plates on the diagram.

(iii) Calculate the force on an electron between the plates when the electric field strength has a value of $2.5 \times 10^3 \text{ NC}^{-1}$. 

\[ \text{Force} = qE \]

where $q$ is the charge of the electron and $E$ is the electric field strength.
The diagram shows two isolated electrons, X and Y, initially at rest in a vacuum. The initial separation of the electrons is 5.0 mm. The electrons subsequently move apart in the directions shown.

(i) Show that the initial electric force acting on each electron due to the other is approximately $9 \times 10^{-24}$ N.

(ii) Calculate the initial acceleration of one electron due to the force in (c)(i).

(iii) Discuss the motion of one electron after it begins to move.

(iv) The diagram shows Y as seen from X, at one instant. Y is moving into the plane of the paper. For this instant, draw on the diagram the shape and direction of the magnetic field produced by Y.
This question is about magnetic fields.

A long straight vertical conductor carries an electric current. The conductor passes through a hole in a horizontal piece of paper.

11a. State how a magnetic field arises. [1 mark]

11b. On the diagram below, sketch the magnetic field pattern around the long straight current-carrying conductor. The direction of the current is into the plane of the paper. [2 marks]
This question is in two parts. **Part 1** is about a lighting system. **Part 2** is about a satellite.

**Part 1** Lighting system

12a. State Ohm’s law. [1 mark]
A lighting system is designed so that additional lamps can be added in parallel.

(i) Determine the maximum number of lamps that can be connected in parallel in the circuit without melting the fuse.

(ii) Calculate the resistance of a lamp when operating at its normal brightness.

(iii) By mistake, a lamp rated at 12V, 9W is connected in parallel with three lamps rated at 6V, 9W. Estimate the resistance of the circuit stating any assumption that you make.
**Part 2 Electric potential difference and electric circuits**

13a. Ionized hydrogen atoms are accelerated from rest in the vacuum between two vertical parallel conducting plates. The potential difference between the plates is \( V \). As a result of the acceleration each ion gains an energy of \( 1.9 \times 10^{-18} \text{J} \).

Calculate the value of \( V \).

\[ \text{[2 marks]} \]

13b. The plates in (a) are replaced by a cell that has an emf of 12.0 V and internal resistance 5.00 \( \Omega \). A resistor of resistance \( R \) is connected in series with the cell. The energy transferred by the cell to an electron as it moves through the resistor is \( 1.44 \times 10^{-18} \text{J} \).

(i) Define resistance of a resistor.

(ii) Describe what is meant by internal resistance.

(iii) Show that the value of \( R \) is 15.0 \( \Omega \).

(iv) Calculate the total power supplied by the cell.

\[ \text{[8 marks]} \]