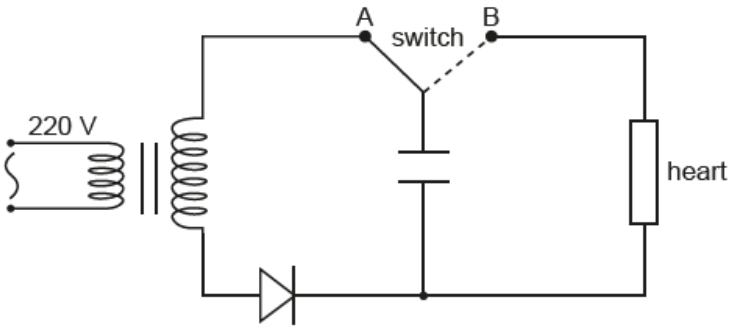
Yellow 3 [HL only] *[68 marks]*

A device sends an impulse of electrical energy to maintain a regular heartbeat in a person. The device is powered by an alternating current (ac) supply connected to a step-up transformer that charges a capacitor of capacitance 30 μF.



1a. Explain the role of the diode in the circuit when the switch is at position A. *[2 marks]*

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The voltage across the primary coil of the transformer is 220 V. The number of turns on the secondary coil is 15 times greater than the number of turns on the primary coil.

1b. Show that the maximum energy stored by the capacitor is about 160 J. *[2 marks]*

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1c. Calculate the maximum charge Q_0 stored in the capacitor. *[1 mark]*

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1d. Identify, using the label + on the diagram, the polarity of the capacitor. *[1 mark]*

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The switch is moved to position B.

1e. Describe what happens to the energy stored in the capacitor when the switch is moved to position B. *[1 mark]*

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1f. Show that the charge remaining in the capacitor after a time equal to one time constant τ of the circuit will be $0.37\,Q_0$. *[1 mark]*

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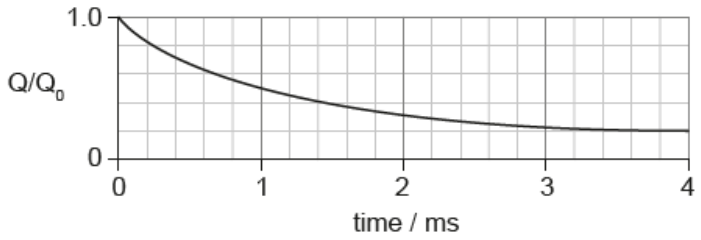
1g. The graph shows the variation with time of the charge in the capacitor as it is being discharged through the heart. *[2 marks]*



Determine the electrical resistance of the closed circuit with the switch in position B.

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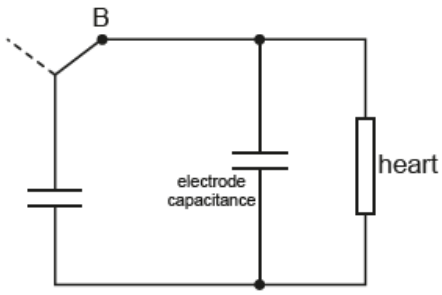
1h. In practice, two electrodes connect the heart to the circuit. These electrodes introduce an additional capacitance. *[2 marks]*



Explain the effect of the electrode capacitance on the discharge time.

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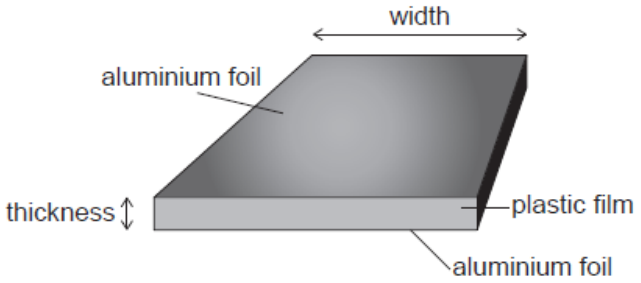
A student makes a parallel-plate capacitor of capacitance 68 nF from aluminium foil and plastic film by inserting one sheet of plastic film between two sheets of aluminium foil.

diagram not to scale



The aluminium foil and the plastic film are 450 mm wide.

The plastic film has a thickness of 55 μm and a permittivity of 2.5×10^{-11} C^2 N^{-1} m^{-2}.

2a. Calculate the total length of aluminium foil that the student will require. *[3 marks]*

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2b. The plastic film begins to conduct when the electric field strength in it exceeds 1.5 MN C^{-1}. Calculate the maximum charge that can be stored on the capacitor. *[2 marks]*

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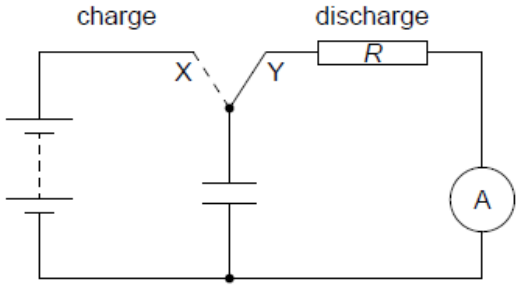
The student uses a switch to charge and discharge the capacitor using the circuit shown. The ammeter is ideal.



The emf of the battery is 12 V.

2c. The resistor *R* in the circuit has a resistance of 1.2 kΩ. Calculate the time taken for the charge on the capacitor to fall to 50 % of its fully charged value. *[3 marks]*

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2d. The ammeter is replaced by a coil. Explain why there will be an induced emf in the coil while the capacitor is discharging. *[2 marks]*

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2e. Suggest **one** change to the discharge circuit, apart from changes to the coil, that will increase the maximum induced emf in the coil. *[2 marks]*

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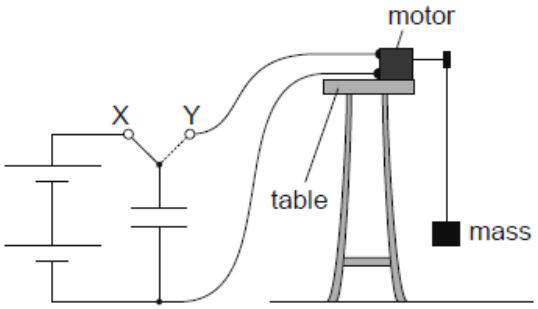
A small electric motor is used with a 12 mF capacitor and a battery in a school experiment.



When the switch is connected to X, the capacitor is charged using the battery. When the switch is connected to Y, the capacitor fully discharges through the electric motor that raises a small mass.

3a. The battery has an emf of 7.5 V. Determine the charge that flows through the motor when the mass is raised. *[1 mark]*

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3b. The motor can transfer one-third of the electrical energy stored in the capacitor into gravitational potential energy of the mass. Determine the maximum height through which a mass of 45 g can be raised. *[2 marks]*

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3c. An additional identical capacitor is connected in series with the first capacitor and the charging and discharging processes are repeated. Comment on the effect this change has on the height and time taken to raise the 45 g mass. *[3 marks]*

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A capacitor consists of two parallel square plates separated by a vacuum. The plates are 2.5 cm × 2.5 cm squares. The capacitance of the capacitor is 4.3 pF.

4a. Calculate the distance between the plates. *[1 mark]*

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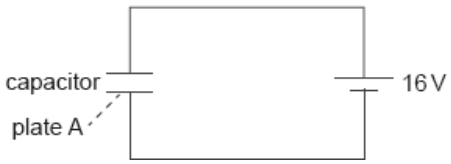
4b. The capacitor is connected to a 16 V cell as shown. *[2 marks]*

diagram not to scale



Calculate the magnitude and the sign of the charge on plate A when the capacitor is fully charged.

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4c. The capacitor is fully charged and the space between the plates is then filled with a dielectric of permittivity $\varepsilon = 3.0\varepsilon_0$. *[2 marks]*

Explain whether the magnitude of the charge on plate A increases, decreases or stays constant.

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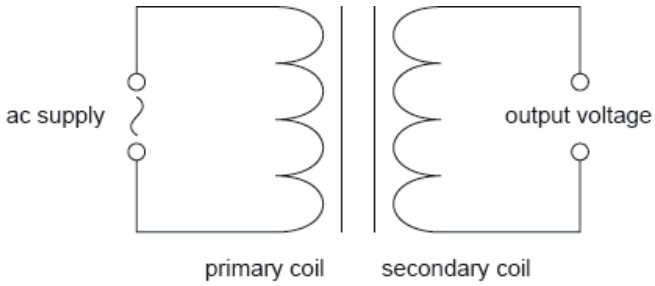
4d. In a different circuit, a transformer is connected to an alternating current (ac) supply. *[3 marks]*



The transformer has 100 turns in the primary coil and 1200 turns in the secondary coil. The peak value of the voltage of the ac supply is 220 V. Determine the root mean square (rms) value of the output voltage.

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4e. Describe the use of transformers in electrical power distribution. *[3 marks]*

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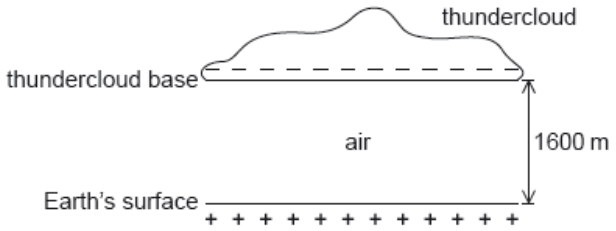
A negatively charged thundercloud above the Earth's surface may be modelled by a parallel plate capacitor.



The lower plate of the capacitor is the Earth's surface and the upper plate is the base of the thundercloud.

The following data are available.

Area of thundercloud base	$= 1.2 \times 10^{8} \mathrm{m}^{2}$
Charge on thundercloud base	$= -25 \mathrm{C}$
Distance of thundercloud base from Earth's surface	$= 1600 \mathrm{m}$
Permittivity of air	$= 8.8 \times 10^{-12} \mathrm{F m}^{-1}$

5a. Show that the capacitance of this arrangement is $C = 6.6 \times 10^{-7}$ F. *[1 mark]*

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5b. Calculate in V, the potential difference between the thundercloud and the Earth's surface. *[2 marks]*

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5c. Calculate in J, the energy stored in the system. *[2 marks]*

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Lightning takes place when the capacitor discharges through the air between the thundercloud and the Earth's surface. The time constant of the system is 32 ms. A lightning strike lasts for 18 ms.

5d. Show that about –11 C of charge is delivered to the Earth's surface. *[3 marks]*

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5e. Calculate, in A, the average current during the discharge. *[1 mark]*

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5f. State **one** assumption that needs to be made so that the Earth-thundercloud system may be modelled by a parallel plate capacitor. *[1 mark]*

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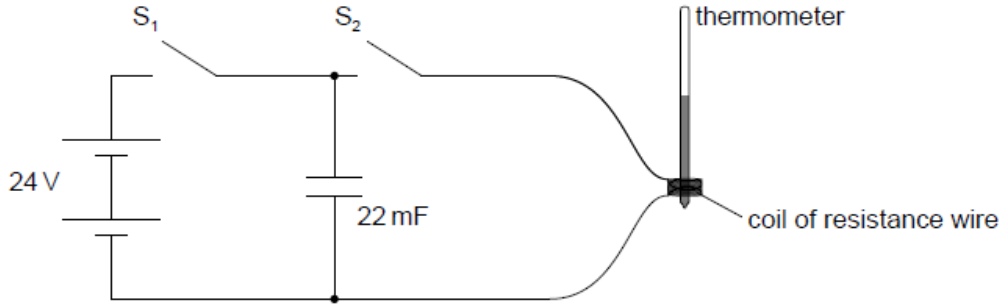
The electrical circuit shown is used to investigate the temperature change in a wire that is wrapped around a mercury-in-glass thermometer.



A power supply of emf (electromotive force) 24 V and of negligible internal resistance is connected to a capacitor and to a coil of resistance wire using an arrangement of two switches. Switch S_1 is closed and, a few seconds later, opened. Then switch S_2 is closed.

6a. The capacitance of the capacitor is 22 mF. Calculate the energy stored in the capacitor when it is fully charged. *[1 mark]*

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6b. The resistance of the wire is 8.0 Ω. Determine the time taken for the capacitor to discharge through the resistance wire. Assume that the capacitor is completely discharged when the potential difference across it has fallen to 0.24 V. *[3 marks]*

6c. The mass of the resistance wire is 0.61 g and its observed temperature rise is 28 K. Estimate the specific heat capacity of the wire. Include an appropriate unit for your answer. *[2 marks]*

6d. Suggest **one** other energy loss in the experiment and the effect it will have on the value for the specific heat capacity of the wire. *[2 marks]*

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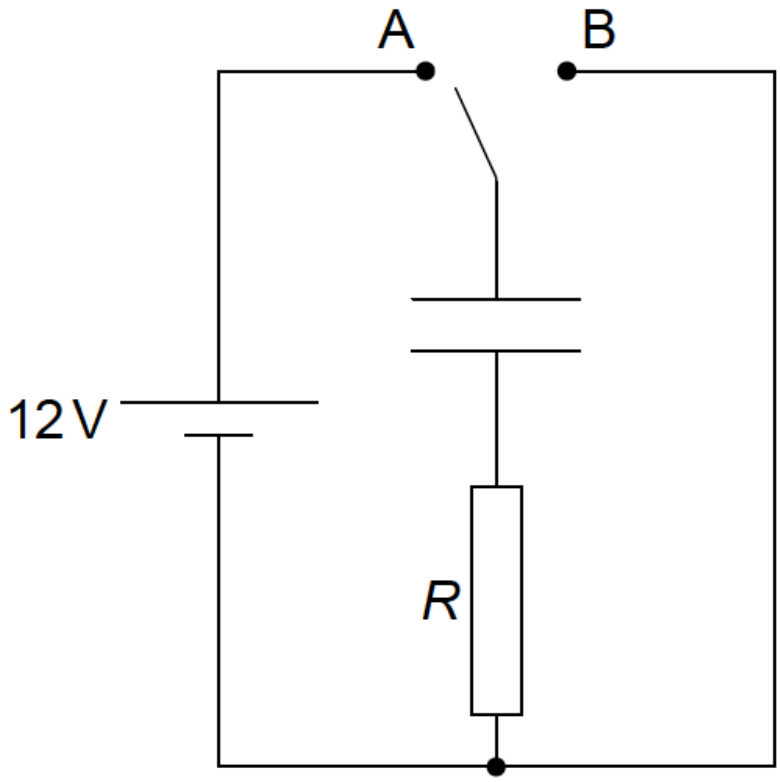
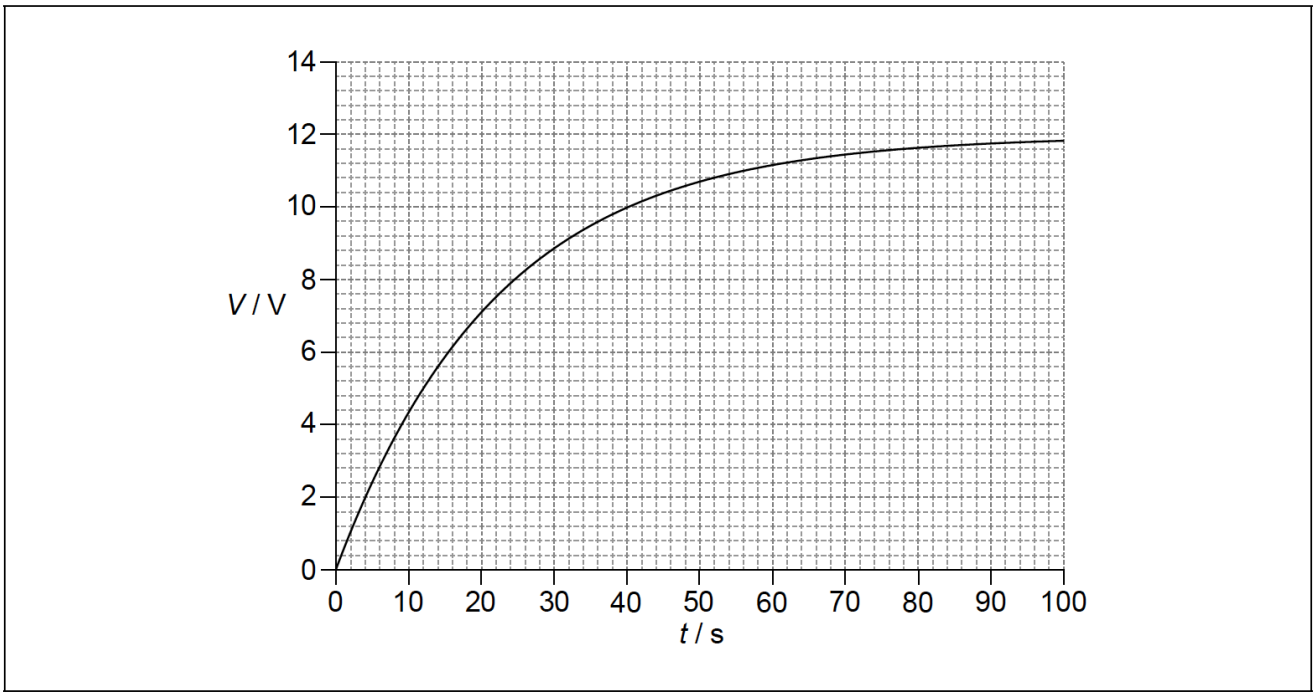
An uncharged capacitor in a vacuum is connected to a cell of emf 12V and negligible internal resistance. A resistor of resistance *R* is also connected.



At *t*=0 the switch is placed at position A. The graph shows the variation with time *t* of the voltage *V* across the capacitor. The capacitor has capacitance 4.5μF in a vacuum.



7a. On the axes, draw a graph to show the variation with time of the voltage across the resistor. *[2 marks]*

7b. (i) The time constant of this circuit is 22s. State what is meant by the time constant. *[2 marks]*

(ii) Calculate the resistance R.

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7c. A dielectric material is now inserted between the plates of the fully charged capacitor. State the effect, if any, on *[2 marks]*

(i) the potential difference across the capacitor.

(ii) the charge on one of the capacitor plates.

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7d. (i) The permittivity of the dielectric material in (c) is twice that of a vacuum. Calculate the energy stored in the capacitor when it is fully charged. *[3 marks]*

(ii) The switch in the circuit is now moved to position B and the fully charged capacitor discharges. Describe what happens to the energy in (d)(i).

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