Chapter 18 – D.C. Circuits

Subject content

Content

- Current and potential difference in circuits
- Series and parallel circuits
- Potential divider circuit
- Thermistor and light-dependent resistor

Learning outcomes

(a) draw circuit diagrams with power sources (cell, battery, d.c. supply or a.c. supply), switches, lamps, resistors (fixed and variable), variable potential divider (potentiometer), fuses, ammeters and voltmeters, bells, light-dependent resistors, thermistors and light-emitting diodes

(b) state that the current at every point in a series circuit is the same and apply the principle to new situations or to solve related problems

(c) state that the sum of the potential differences in a series circuit is equal to the potential difference across the whole circuit and apply the principle to new situations or to solve related problems

(d) state that the current from the source is the sum of the currents in the separate branches of a parallel circuit and apply the principle to new situations or to solve related problems

(e) state that the potential difference across the separate branches of a parallel circuit is the same and apply the principle to new situations or to solve related problems

(f) recall and apply the relevant relationships, including $R = V/I$ and those for current, potential differences and resistors in series and in parallel circuits, in calculations involving a whole circuit

(g) describe the action of a variable potential divider (potentiometer)

(h) describe the action of thermistors and light-dependent resistors and explain their use as input transducers in potential dividers

(i) solve simple circuit problems involving thermistors and light-dependent resistors

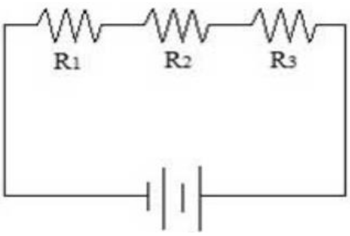
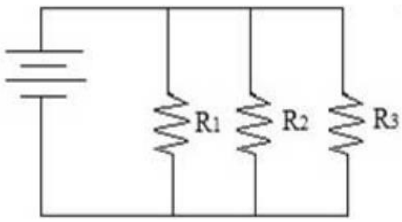
Definitions

Term	Definition
Potential divider	Line of resistors connected in series. Used to provide a fraction of voltage of source to another part of circuit
Input transducer	Electronic device that convert non-electrical to electrical energy

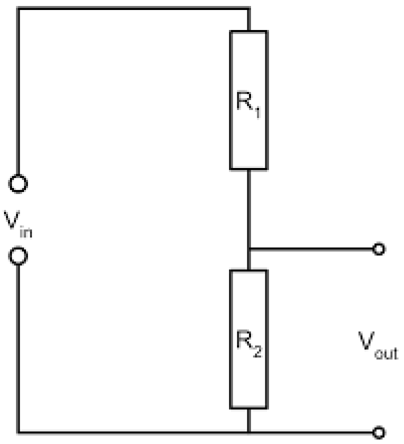
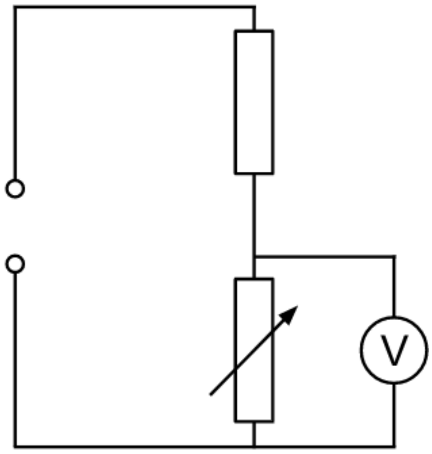
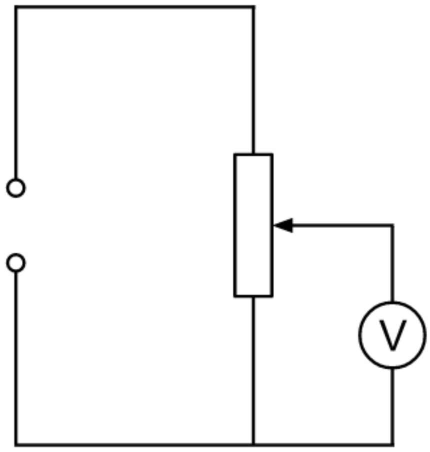
Formulae

Current (series)	p.d. (series)	Resistance (series)
$I_1 = \ldots = I_n$	$V_T = V_1 + \ldots + V_n = \varepsilon$	$R_T = R_1 + \ldots + R_n$
Current (parallel)	**p.d. (parallel)**	**Resistance (parallel)**
$I_T = I_1 + \ldots + I_n$	$V_T = V_1 = \ldots = V_n$	$\frac{1}{R_T} = \frac{1}{R_1} + \cdots + \frac{1}{R_n}$
Potential divider	**Potentiometer**	
$V_{out} = \frac{R_2}{R_1 + R_2} \times V_\varepsilon$	$V_{out} = \frac{AC}{AC + BC} \times V_\varepsilon$	

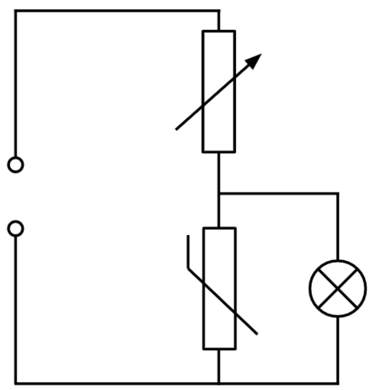
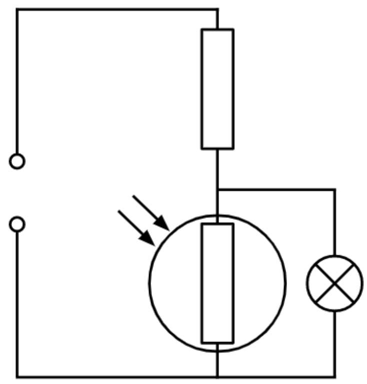
18.1 Series and Parallel Circuits

Aspect	**Series circuit**	**Parallel circuit**
Current	$I_1 = \ldots = I_n$ (equal)	$I_T = I_1 + \ldots + I_n$ (sum)
Potential difference	$V_T = V_1 + \ldots + V_n = \varepsilon$ (sum)	$V_T = V_1 = \ldots = V_n$ (equal)
Resistance	$R_T = R_1 + \ldots + R_n$ (sum)	$\frac{1}{R_T} = \frac{1}{R_1} + \cdots + \frac{1}{R_n}$ (reciprocal sum)
Figure		

18.2 Potential Divider

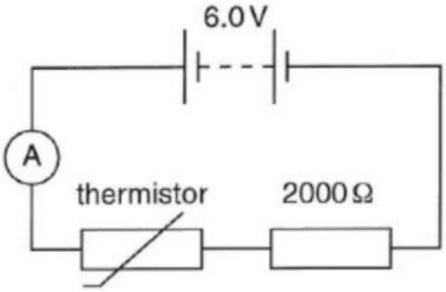
2 fixed resistors	Rheostat	Potentiometer
		

18.3 Transducers

Thermistor	Light-dependent resistor (LDR)
<u>Thermal</u> → electrical energy	**<u>Light</u>** → electrical energy
Temperature ↑ resistance ↓	Light intensity ↑ resistor ↓
Switch to turn temperature alarms on / off	Light meter, automatic street lights
	

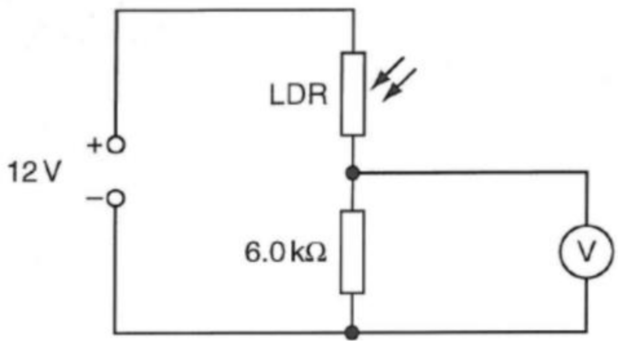
Typical questions:

The figure below shows a thermistor in a potential divider circuit that is used to monitor temperature. The fixed resistor has a resistance of 2000 Ω.



- When the temperature rises, resistance of thermistor decreases.
- The thermistor and fixed resistor are forming a potential divider circuit. The voltage across the thermistor V_{TH}, is found by the equation $V_{TH} = \frac{R_{TH}}{R+R_{TH}} \times V_{total}$.
- Since resistance of the thermistor R_{TH} decreases, V_{TH} across thermistor decreases.

A potential divider is made from a light-dependent resistor (LDR) and a fixed resistor. The potential divider is connected in series with a 12 V d.c. power supply, and a voltmeter is connected across the 6.0 kΩ resistor. The figure below shows the circuit diagram.



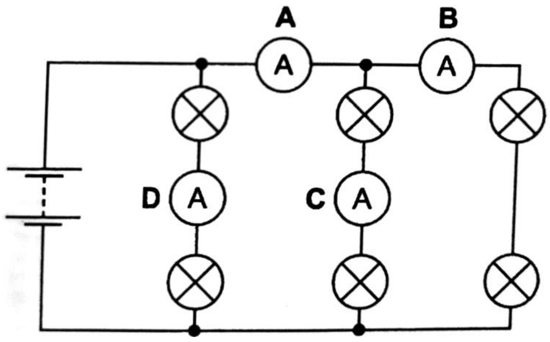
A light shines on the LDR. The brightness of the light on the LDR is gradually increased. State and explain what happens to the reading on the voltmeter.

- Voltmeter reading increases.
- When the brightness increases, resistance of LDR decreases.
- The LDR and fixed resistor are forming a potential divider circuit.
- Hence, a smaller fraction of total voltage is now across LDR and the voltage across fixed resistor increases as sum of voltages remains constant.

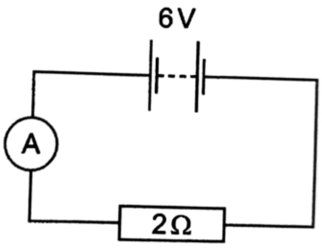
Typical questions

Multiple choice questions

1 The diagram below shows six identical lamps, four ammeters and a battery.
The current in the battery is 1.5 A.
Which ammeter reads 1.0 A? (2012 P1 Q31)



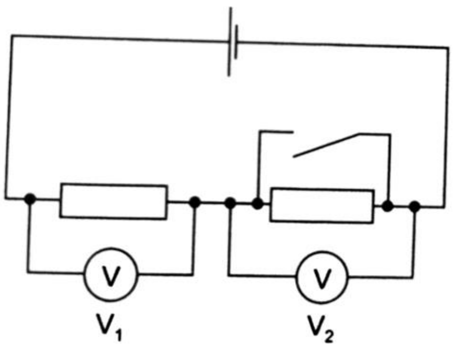
2 In the circuit shown, the ammeter reading is 3 A.



What is the ammeter reading when a resistor of 2000 Ω is connected in parallel with the 2 Ω resistor? (2012 P1 Q32)

A slightly less than 3 mA
B slightly more than 3 mA
C slightly less than 3 A
D slightly more than 3 A

3 The diagram shows a circuit.

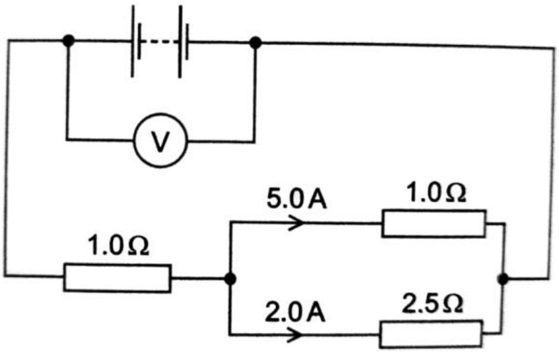


When the switch is closed, what happens to the readings of voltmeters V1 and V2? (2014 P1 Q31)

	V_1	V_2

A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

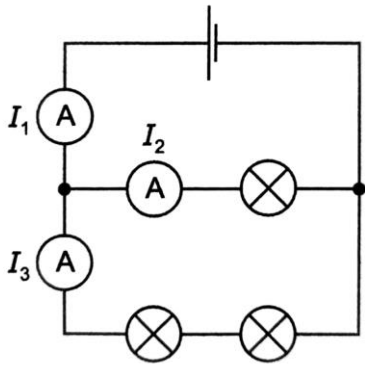
4 The circuit diagram shows a 1.0 Ω resistor in series with a parallel arrangement of a 1.0 Ω resistor and a 2.5 Ω resistor.



The currents in the two parallel resistors are shown.
What is the reading on the voltmeter? (2015 P1 Q33)

A 7.0 V
B 10 V
C 12 V
D 17 V

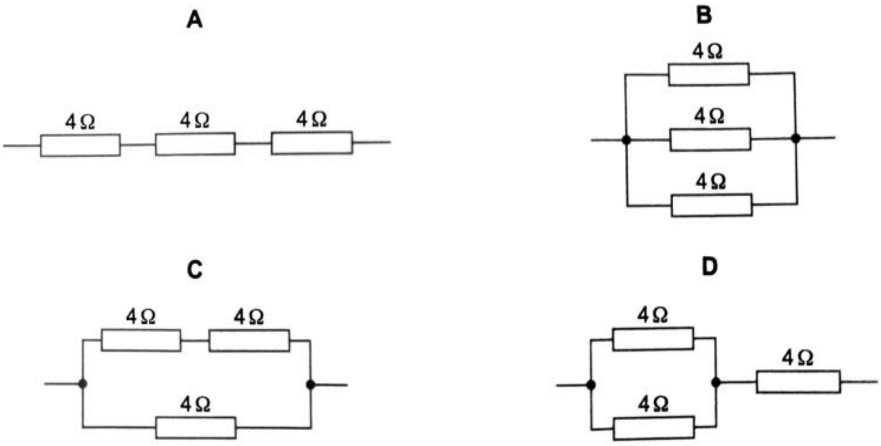
5 Three identical lamps and three identical ammeters are connected as shown.



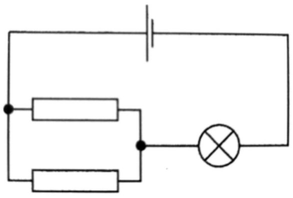
The readings on the ammeters are I_1, I_2 and I_3.
How are the readings related? (2016 P1 Q32)

A $I_1 = I_2 = I_3$
B $I_1 > I_2$ and $I_2 = I_3$
C $I_1 > I_3 > I_2$
D $I_1 > I_2 > I_3$

6 Three resistors, each of resistance 4 Ω, are connected in different combinations.
Which combination has a resistance of 6 Ω? (2016 P1 Q33)



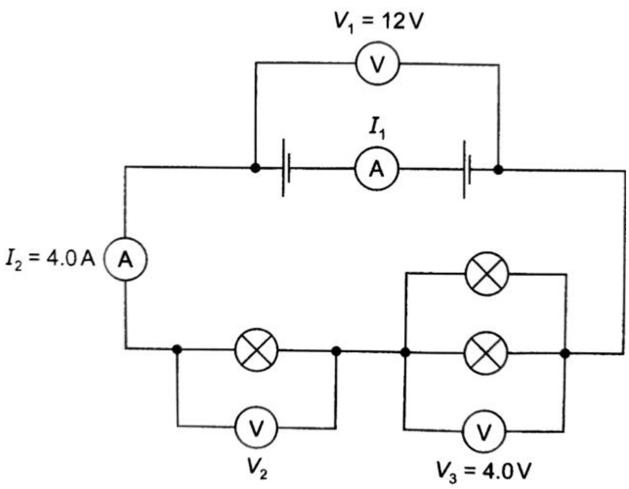
7 A student connects a circuit that contains two resistors in parallel, a lamp and a cell.



The student adds a third resistor in parallel with the two resistors already in the circuit.
What happens to the potential difference (p.d.) across the lamp and the total resistance of the circuit? (2018 P1 Q30)

	p.d. across lamp	resistance of circuit
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

8 A student sets up the circuit shown.

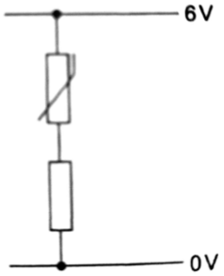


What are the current I_1 and the potential difference V_2? (2019 P1 Q35)

	I_1 / A	V_2 / V

A	0	4.0
B	0	8.0
C	4.0	4.0
D	4.0	8.0

9 The diagram shows a thermistor connected in a potential divider circuit.

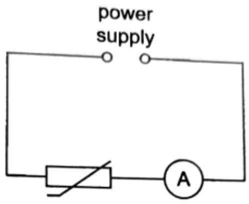


The resistance of the thermistor decreases when its temperature rises. The thermistor is heated. What happens to the potential difference across the thermistor as it is heated?

(2011 P1 Q39)

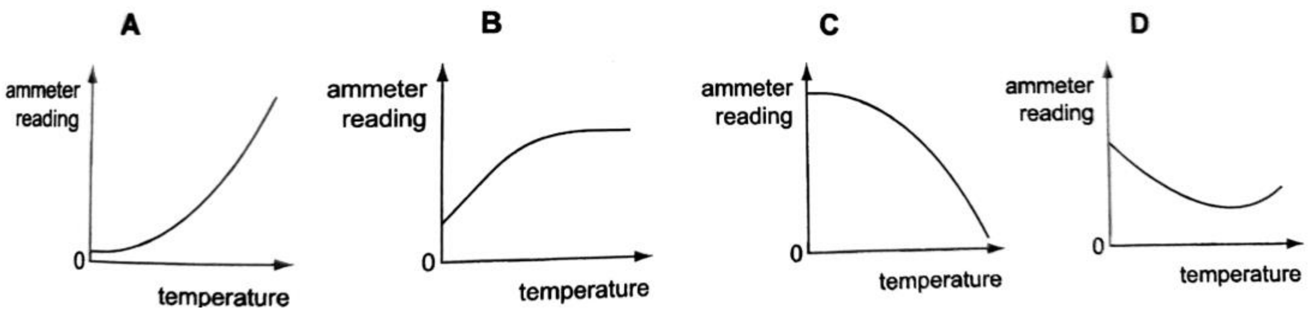
A It decreases, but not to zero.
B It decreases to zero.
C It increases, but not to zero.
D It increases to 6 V.

10 The diagram shows a circuit containing a thermistor. The resistance of the thermistor decreases as its temperature increases.



Which graph shows how the ammeter reading changes as the temperature of the thermistor rises?

(2012 P1 Q34)

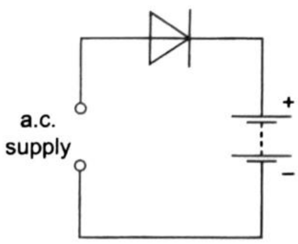


11 A car battery supplies a current in one direction. A current in the opposite direction recharges the battery.

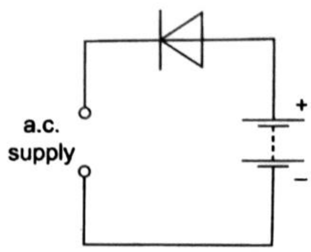
Which circuit recharges the battery, using an alternating current (a.c.) supply and a diode?

(2013 P1 Q34)

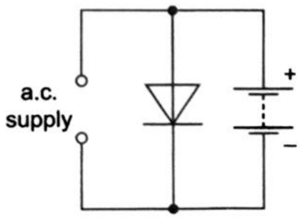
A



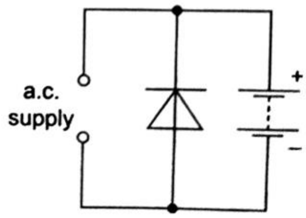
B



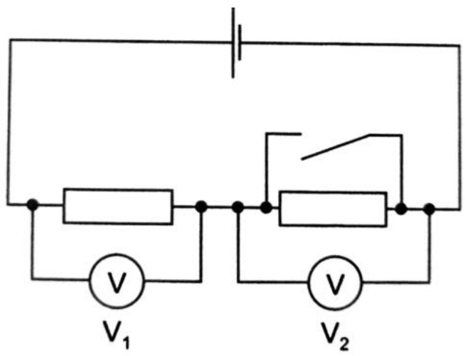
C



D



12 The diagram shows a circuit.

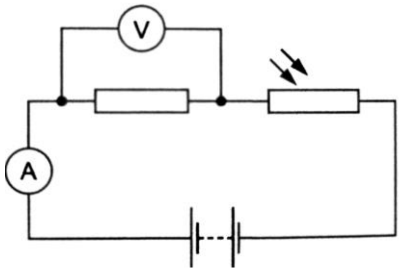


When the switch is closed, what happens to the readings of voltmeters V_1 and V_2?

(2014 P1 Q31)

	V_1	V_2
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

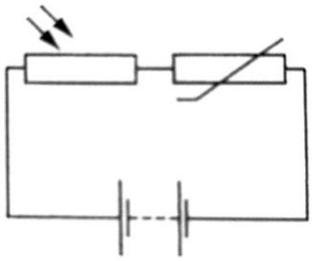
13 A resistor and a light-dependent resistor (LDR) are connected in series with a battery, as shown.



When very bright light is shone on the LDR, the readings on both the ammeter and the voltmeter change.
How do they change? (2015 P1 Q34)

	reading on ammeter	reading to voltmeter
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

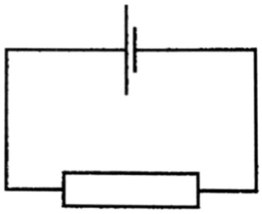
14 A light-dependent resistor (LDR) and a thermistor are connected in series with a battery.



Which conditions cause the potential difference (p.d.) across the thermistor to be the largest? (2017 P1 Q35)

A dark and cold
B dark and hot
C bright and cold
D bright and hot

15 The diagram shows a cell connected to a resistor.

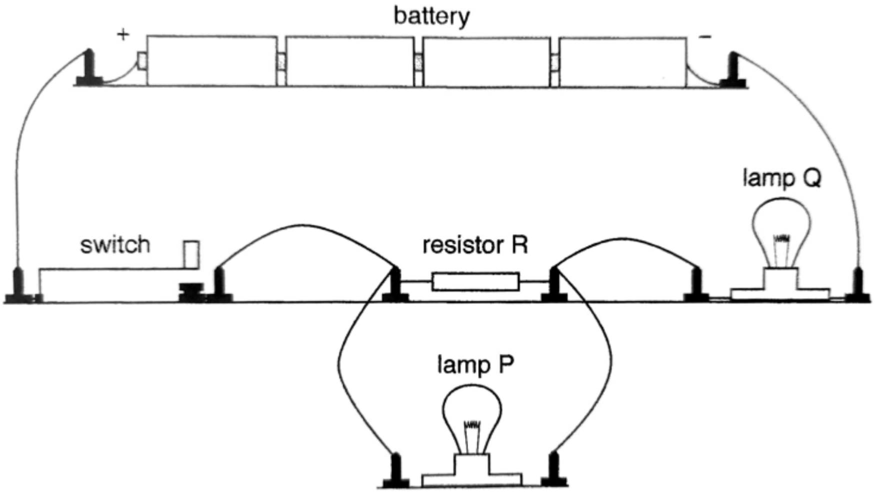


A voltmeter is used to measure the p.d. across the cell. The voltmeter does not affect the current in the cell.
What is the position and the resistance of a voltmeter in the electrical in the electric circuit? (2018 P1 Q32)

	position	resistance
A	in parallel with the resistor	very high
B	in parallel with the resistor	very low
C	in series with the resistor	very high
D	in series with the resistor	very low

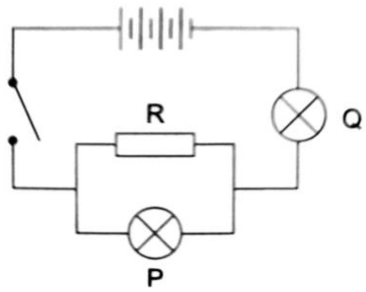
Structured questions

1 A student sets up a circuit using a battery made of four cells, a resistor R, two identical lamps P and Q, and a switch. The circuit is shown in the figure below.



(2018 P2A Q6)

(a) Draw a circuit diagram of this circuit using electrical symbols for the components. [2]



(b) The switch is closed. The current in lamp P is 0.25 A and there is a potential difference (p.d.) of 1.5 V across its terminals.
Calculate the resistance of lamp P. [2]

R = V / I = 1.5 / 0.25 = <u>**6 Ω**</u>

(c) The resistance of resistor R is 18 Ω.
The combined resistance of P, Q and R in the circuit is 12 Ω.
Calculate the resistance of lamp Q. [2]

Consider total resistance in circuit:

$(1/R_P + 1/R_R)^{-1} + R_Q = 12$
$(1/6 + 1/18)^{-1} + R_Q = 12$

$R_Q = 12 - (1/6 + 1/18)^{-1} = 12 - 4.5 =$ **7.5 Ω**

(d) Explain why in this circuit,

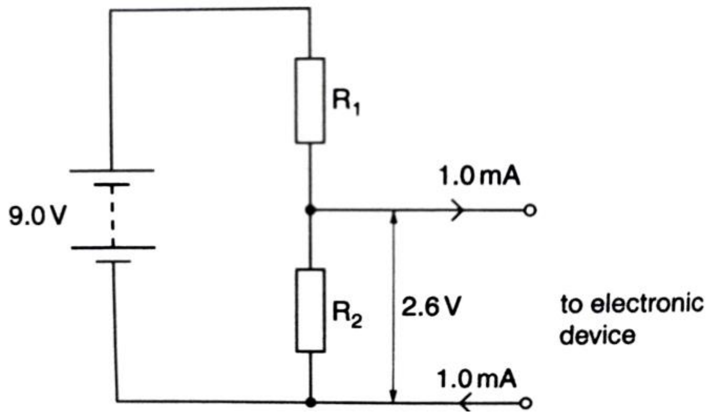
(i) the current in lamp Q is larger than the current in lamp P [1]

The current in Q is equal to the sum of the currents from P and R.

(ii) lamp Q has a different resistance from lamp P, even though they are identical lamps. [2]

Due to the larger current in Q, lamp Q operates at a higher temperature.
As the filament lamp is a non-ohmic conductor, the increase in temperature for Q results in higher resistance.

2 An electronic device requires a potential difference (p.d.) of 2.6 V.
The only power source available is a battery of electromotive force (e.m.f.) 9.0 V.
The potential divider circuit shown in the figure below is used. This includes two resistors R_1 and R_2.
The current in the electronic device is 1.0 mA.



(2014 P2B Q11 EITHER)

(a) Explain what is meant by

(i) e.m.f. [1]

e.m.f. refers to electromotive force, which is the amount of energy converted from non-electrical forms to electrical forms when 1 coulomb of charge passes through the component.

(ii) p.d. [1]

p.d. refers to potential difference across two points in a circuit, which is the amount of

<u>energy converted from electrical forms to non-electrical forms, when 1 coulomb of charge passes between the two points.</u>

(b) Determine the value of the p.d. across the resistor R_1. [1]

p.d. across R_1 = 9.0 – 2.6 = **<u>6.4 V</u>**

(c) The resistance of 500 Ω. Calculate

(i) the current in R_1 [2]

I = V / R = 6.4 / 500 = **<u>12.8 mA</u>**

(ii) the current in R_2 [1]

I = 12.8 – 1.0 = **<u>11.8 mA</u>**
(Note: As the current is in the electronic device of 1.0 mA is flowing in an opposite direction to the current flowing in the circuit, we have to take the vector sum of the currents.)

(iii) the resistance of R_2 [1]

R_2 = V / I = 2.6 / 0.0118 = **<u>220 Ω</u>**

(d) To increase the life of the battery, R_1 is replaced by a resistor which has a resistance of 6000 Ω. The same battery is used.

(i) Explain why this increases the life of the battery. [1]

<u>As the resistance is now higher than before, the current flowing in the circuit is reduced, thus increasing the life of the battery.</u>

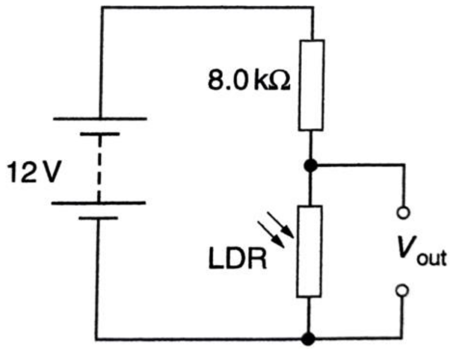
(ii) Without further calculation, state one change needed in the circuit to keep the p.d. across the electronic device at 2.6 V. [1]

<u>Increase the resistance of R_2</u>

(iii) Explain why the value of R_1 cannot be increased much above 6000 Ω. [1]

<u>When R_1 has a resistance of 6000 Ω, the current in the circuit is only 1.07 mA. If it is increased further, the current supplied to the electronic device would be affected.</u>

3 The figure below is a circuit diagram. The circuit uses a light-dependent resistor (LDR) and a fixed resistor of resistance 8.0 kΩ.



The LDR has a resistance of 600 Ω in bright light. (2016 P2A Q7)

(a) Calculate the output voltage V_{out} when the LDR is in bright light. [2]

$V_{out} = \frac{600}{600 + 8000} \times 12\text{ V} = \underline{\mathbf{0.837\text{ V}}}$

(b) In dim light, V_{out} is 8.0 V. For this level of brightness, determine

(i) the voltage across the fixed resistor [1]

$V_{8\text{ k}\Omega} = V_{total} - V_{out} = 12 - 8 = \underline{\mathbf{4\text{ V}}}$

(ii) the resistance of the LDR [1]

Ratio of voltage = ratio of resistances

$$\frac{V_{8\,k\Omega}}{V_{LDR}} = \frac{R_{8\,k\Omega}}{R_{LDR}}$$

$$\frac{V_{8\,k\Omega}}{V_{LDR}} = \frac{R_{8\,k\Omega}}{R_{LDR}}$$

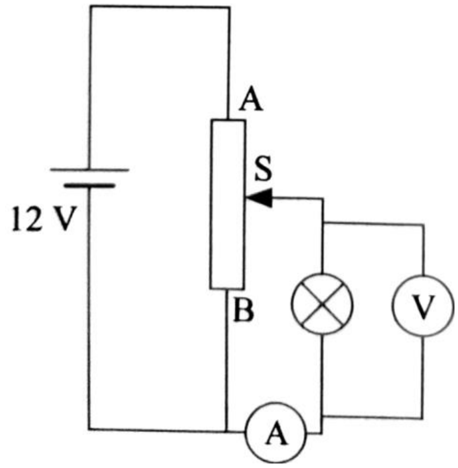
$R_{LDR} = 8000 \times 8/4 = 16000\ \Omega = \underline{\mathbf{16\text{ k}\Omega}}$

(c) The output voltage V_{out} is connected to an electronic switch and lamp. The lamp switches on when V_{out} is larger than 8.0 V.
The positions of the LDR and the fixed resistor are swapped. Describe and explain the operation of the new device as the level of light falls. [2]

- <u>In bright light, the voltage across the LDR is 0.837 V (from (a)), this means V_{out} is 11.163 V, which means the lamp is switched on. As the level of light falls, the resistance of the LDR increases, reducing V_{out}. This may reduce the brightness of the lamp.</u>
- <u>When light reduces to a level such that the resistance of the LDR reaches 4 kΩ, V_{out} = 8 V, the lamp switches off. As the level of light reduces further, the lamp switches off.</u>

4 A student investigates how the current in a filament lamp varies as the potential difference (p.d.) across it is changed from 0 to 12 V. The student uses a 12 V battery, an ammeter, a voltmeter and a variable potential divider (potentiometer) for the experiment. (2012 P2B Q10)

(a) Draw a suitable circuit diagram for the experiment. [3]



(b) The student increases the current in the lamp.

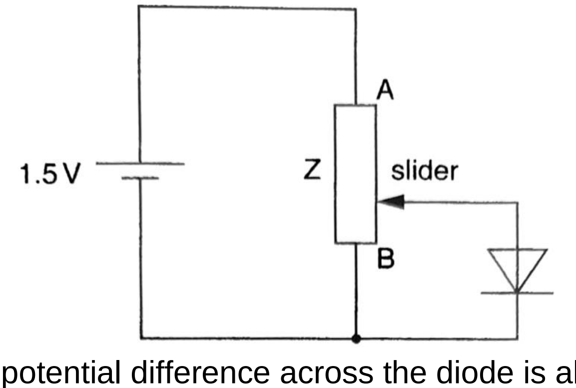
1. Explain how the student gradually increases the current in the lamp from zero. [1]

The student puts the sliding contact S at position B first, and slowly moves the contact towards A, in order to increase the current in the lamp.

2. Explain why the p.d. across the lamp is not proportional to the current in it. [2]

The lamp is a non-ohmic conductor. As the p.d. across the lamp increases, the resistance of the lamp increases as well. As a result, the change in current is not proportional.

5 A student takes measurements of current and voltage to plot the *I* / *V* characteristic graph of a diode. He connects the diode to a circuit containing a 1.5 V cell and a variable resistor Z.



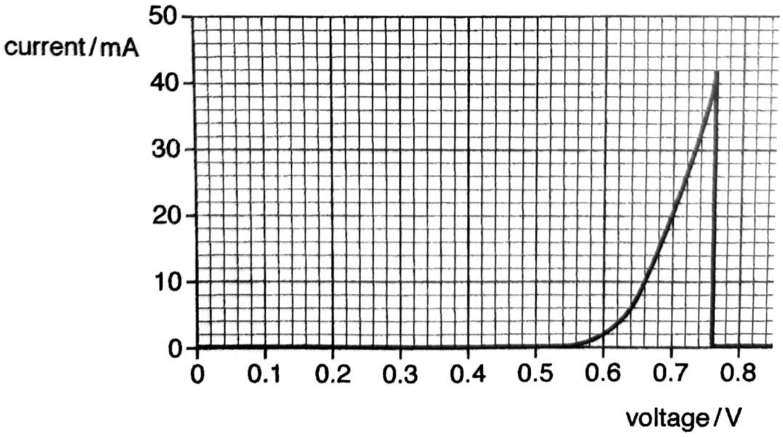
By adjusting the slider, the potential difference across the diode is altered. (2018 P2B Q10)

(a) State the name of the device obtained by using the variable resistor Z in this way. [1]

Potential divider / Potentimeter

(b) On the figure above, add an ammeter and a voltmeter in the correct positions that allow measurements for the *I* / *V* characteristic graph to be taken. [2]

(c) The figure below shows the *I* / *V* characteristic graph obtained.



At currents greater than 42 mA, the diode overheats and stops working.

(i) Using the figure above, describe how the current and the resistance of the diode change as the voltage is increased from 0 to 0.7 V. You are **not** required to make any calculations. [2]

- From V = 0 to 0.55 V, the current remains zero, indicating that the resistance of the diode is infinitely high.
- From V = 0.55 to 0.70 V, the current increases at an increasing rate, from 0 to 21 mA, indicating that the resistance of the diode is reduced in this range.

(ii) Calculate the maximum electrical power that can be supplied to the diode. Give your answer to an approximate number of significant figures. [2]

Max current = 42 mA, voltage = 0.76

P = I × V = $(42 \times 10^{-3})(0.76)$ = 0.03192 W = **0.032 W** (2 s.f.)

(Note: Since the measurements are taken to 2 s.f, the final answer should follow the same number of significant figures as the measurement, which is 2 s.f.)

(d) To obtain the readings, the student moves the slider shown in the circuit diagram above from B to A.
Explain why the student does **not** move the slider from A to B. [1]

When the slider is at A, there is a potential difference of 1.5 V across the diode, as the diode would be in parallel with the 1.5 V cell. Due to the low resistance of the diode when V = 1.5 V, the current is larger than 42 mA, which causes the diode to overheat and stop working. As such, if the student moves the slider from A to B, he would obtain a reading of 0 A throughout.