Chap. 20: D.C. circuits

1. Kirchhoff's first & second law
2. Derive formula of the total effective resistance of resistors arranged in series and parallel
3. Solve problems
   - calculate the total effective resistance in network.
   - determine unknown current in circuit using Kirchhoff's laws
   - involved ammeter (with small internal resistance) & voltmeter (with large internal resistance)
   - calculate variation of electric potential round the circuit
4. Potential divider
   - incorporated with LDR & Thermistor
5. Potentiometer
   - Calculate the length of wire at balance point, the measured emf, resistor in circuit.

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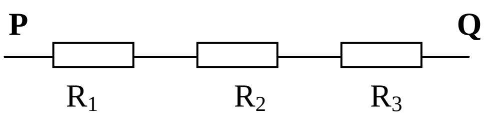
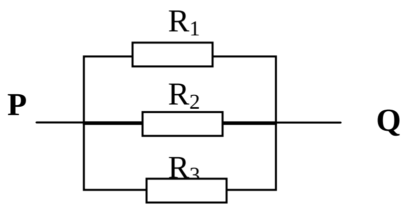
1. Kirchhoff laws

Kirchhoff 1st law (Conservation of charge)	**Kirchhoff 2nd law (Conservation of energy)**
The charge is neither created nor destroyed but is conserved in a closed circuit, since electric charge do not accumulate nor are produced at a point in a network.	Total amount of energy supplied = Total amount of energy dissipated (in a closed loop)

2. Derive equations for combined resistances in series and parallel circuits

Series circuit	**Parallel circuit**
	
By conservation of ________ , charges flow into a resistor must flow out of it and then flowing to next resistor and so on. Thus, in a series circuit, current flowing through each resistor is the same.	Three resistors are arranged in parallel with the _________ battery, giving three closed loops. By conservation of ________, energy dissipated by a unit charge entering each of R_1, R_2 & R_3 is the same. Thus, p.d. drops across each resistor is the same. $V = V_1 = V_2 = V_3$

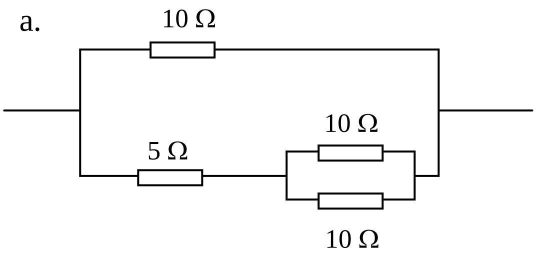
Kirchhoff's 2nd law: the total of p.d. drops across each of the resistors is equal to p.d. V across the points PQ. i.e. $V = V_1 + V_2 + V_3$ (By Ohm's law)	**Kirchhoff's 1st law:** current enters any junction in a circuit = current leaves the junction. i.e. $I = I_1 + I_2 + I_3$ (By Ohm's law)
Total effective resistance/ equivalent resistance R_T: $R_T = R_1 + R_2 + R_3$	**Total effective resistance/ equivalent resistance R_T:** $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

*if N resistors of the same resistance R joined in parallel:

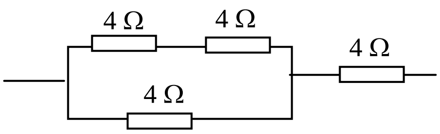
$$R_T = \frac{R}{N}$$

Q1: Calculate the effective resistance of the following circuits:

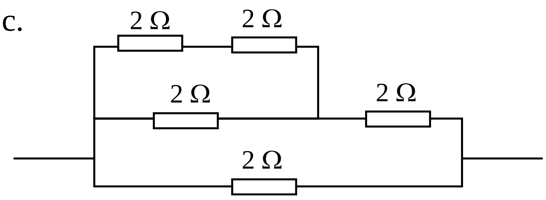
a.



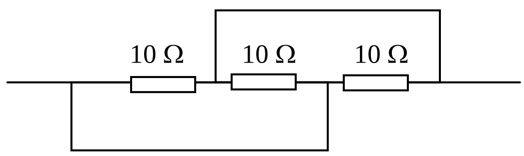
b.



c.



d.

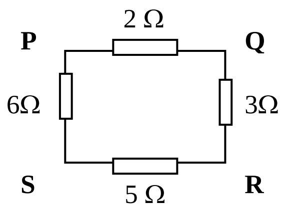


[5Ω, 6.66Ω, 1.25Ω, 3.33Ω]

Q2: Three resistors 1 Ω, 2 Ω and 3 Ω are given. How to arrange these resistors to obtain the

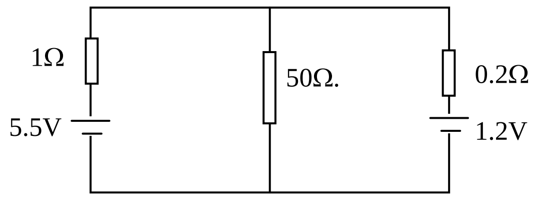
i. maximum effective resistance [6 Ω]
ii. minimum effective resistance [0.545 Ω]

Q3: Between which two points, the effective resistance of the combination is the minimum?



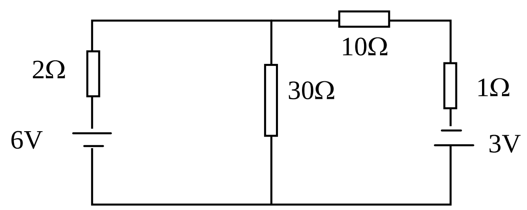
3. Problem solving: Determining unknown current using Kirchhoff's laws

Q1: Calculate the current flowing though 50 Ω. [0.0381A]

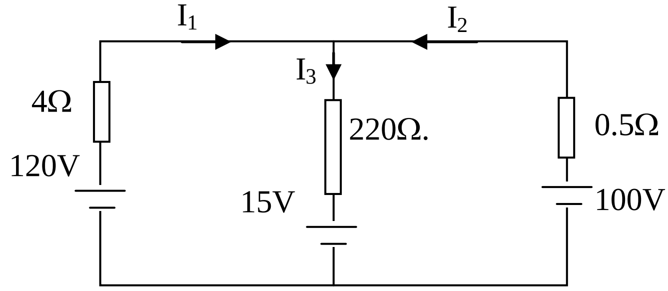


1. Label the current on each series with presumed direction, e.g. I_1, I_2
2. Form an equation for each closed loop where total emf = total p.d. drops along the loop, $\sum E = \sum IR$
3. When the direction of loop is opposite to the presumed direction of current, -ve is assigned.
4. No. of unknown current = no. of equations formed (i.e. no. of loops)
5. Determine unknown current by solving simultaneous equations.

Q2: Calculate the current flowing though 30 Ω. [0.146 A]

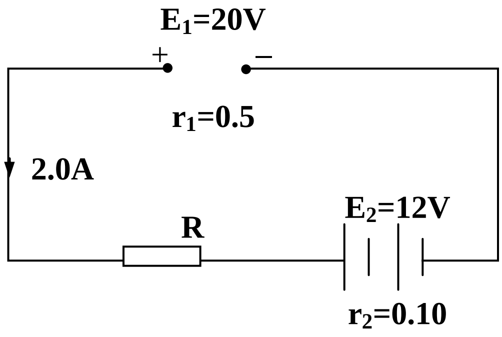


Q3: Using Kirchhoff's 2nd law, write two equations linking any two currents of I_1, I_2 and I_3 in the figure below. Hence, determine the value of I_1, I_2 and I_3.



Q4: A generator of e.m.f. 20 V and internal resistance 0.50 Ω is used to charge a car battery of e.m.f. 12 V and internal resistance 0.10 Ω. They are connected in series together with resistance R whose value is adjusted to give a charging current of 2.0 A.
Calculate:

i. the value of R [3.4Ω]



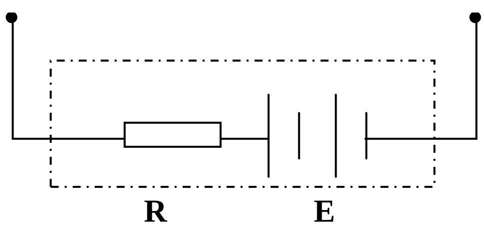
ii. the power supplied by the generator [40W]

iii. the total rate of dissipation of electrical energy [16W]

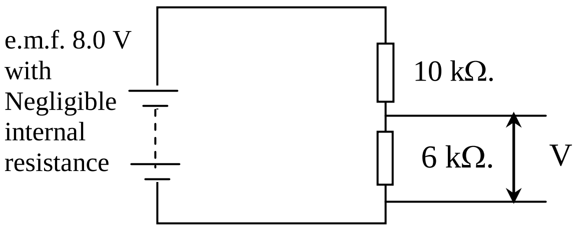
4. Potential divider

▪ It is used to obtain a ______________________ provided by a voltage supply by using:	
i) two separate resistors, R_1 & R_2 connected in series	ii) a variable resistor (wire attached to a metre rule) $V_o = \left(\frac{l_{AC}}{l_{AB}}\right)V_i$; $V_o \propto l_{AC}$
$V_o = \left(\frac{R_1}{R_1 + R_2}\right)V_i$ As higher resistance of R_1 is used, more voltage drops across R_1 i.e. $V_o \propto R_1$	▪ Two fixed terminals A and B at both ends. One slider terminal C. ▪ Input voltage V_i is supplied to the fixed terminal AB. ▪ Any fraction of V_i may be obtained by varying the position of the slider. ▪ V_o maximum is obtained with slider at end B ($V_o = V_i$) ▪ V_o minimum is obtained with slider at end A ($V_o = 0$)

Q1: A battery with an e.m.f. of E and an internal resistance of R is measured by two voltmeters, separately. Voltmeter A has an internal resistance of 10R while Voltmeter B has R.
What is the terminal p.d. of the battery, in terms of E, as measured by voltmeters A and B ?



Q2: A voltmeter with internal resistance 75 kΩ is used to measure the p.d. across the resistor of 6 kΩ. What is the percentage of error in measuring the p.d.? [4.76%]

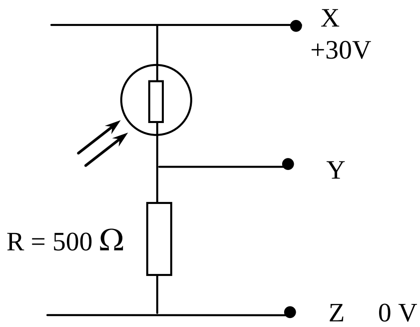


5. Light-dependent resistor (LDR) & Thermistor in Potential divider circuit

	Light-dependent potential divider	Temperature-dependent potential divider
Sensor:	Light-dependent resistor (LDR)	Negative temperature coefficient Thermistor (T↑ R↓)
Symbol & Circuit		
Resistance in the sensor R_S varies with …	Light intensity ↑ Resistance ↓	Temperature ↑ Resistance ↓
Why?	When light shines on the surface of LDR, electrons in the LDR absorb light energy and are liberated for _____________. The stronger the light intensity, more bonds are broken, more electrons are freed for the conduction - the ________ the LDR's resistance	As temperature increases, the electrons of the thermistor gain more _______________ and vibrate more vigorously - break the bond and free some electrons for the conduction of electricity. The ________ the temperature, the more kinetic energy the electrons gain, the ________ the resistance of the thermistor.
Operating concept	▪ In total darkness, no light. ⇒ $\mathbf{R_S}$ is maximum (~100MΩ) ⇒ $\mathbf{V_o}$ is large ▪ In bright light ⇒ $\mathbf{R_S}$ is minimum (<100Ω) ⇒ $\mathbf{V_o}$ is low p.d. across LDR _________ when Intensity increases	▪ Temperature falls, ⇒ R_S is large ⇒ $\mathbf{V_o}$ is large ▪ As temperature rises, ⇒ R_S is small ⇒ V_o is small p.d. across thermistor _________ when temperature increases

	If the fixed resistor is replaced by a variable resistor, this provides manual adjustment of V_0 at a particular light/ heat level. Thus, the device, which the sensor is incorporated into, can be switched on at any desirable light/ heat level.	
Applications:	▪ Automatically switched-on lamp	▪ Fire alarm ▪ Temperature controller in heater, tropical fish tank and incubator.

Q1: The resistance of a light dependent resistance (LDR) is 1 kΩ when it is in the dark but then drops to 100 Ω in bright light.

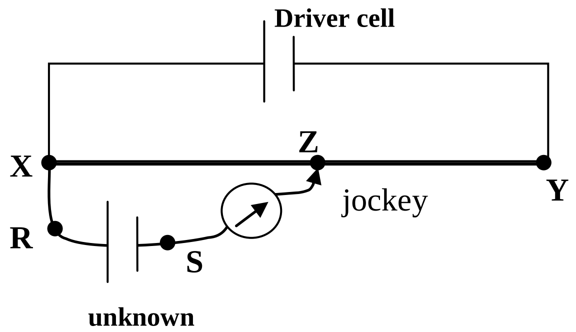


a) What is the corresponding change in the potential at point Y? [+15 V]

b) A lamp is connected, in parallel with the LDR, to the terminal XY and it is lit at normal when a p.d. of 8 V is supplied to it. Resistance of the lamp is 0.6 kΩ at its normal brightness. Calculate the new value of R to be connected to light the lamp automatically when the day is dark. [1030 Ω]

6. Potentiometer (to measure voltage)

- A potential divider circuit can also be set up using a wire of uniform ___________ and a sliding contact. This provides a continually variable p.d. and is known as potentiometer.



Simple potentiometer circuit

- It can be used as a very accurate ___________ to measure terminal p.d. (true emf) of an unknown source.
- A driver cell drives current through the uniform slide-wire, fixed at two ends XY of a metre rule.
- As the wire has uniform __________, the ___________________ between point X and the sliding contact is therefore directly proportional to the _______ of wire *l* between the two points
- The source to be measured is connected with its positive terminal connected to X.
- When the potential difference between point X and the sliding contact ________ the unknown e.m.f., galvanometer shows a ______ reading. The length between point X and the sliding contact is recorded as *l*.
- It is ____________ by a standard cell of known e.m.f. of E_o which is connected across RS and the balance point l_o is recorded. Then, a test cell is connected across RS and the corresponding balance point l_{XZ} is measured.
- There are three possibilities:
  - If the $E_{RS} < E_{XZ}$, current flows from R to S, galvanometer shows deflection.
  - If the $E_{RS} > E_{XZ}$, current flows from S to R, galvanometer shows deflection.
  - If the $E_{RS} = E_{XZ}$, galvanometer reads zero, no current. Balance point l_{XZ} is measured.

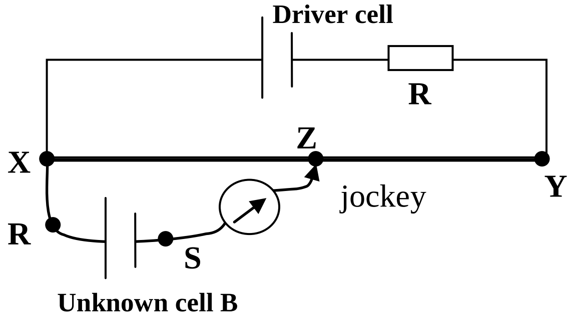
  The unknown p.d. E_{XZ} can be calculated through the equation:

$$\frac{E_{XZ}}{E_o} = \frac{l_{XZ}}{l_o}$$

- It is known as ______________, since at the balance point, no current flows between R and S.

Accuracy of the measurement

- The galvanometer reads zero reading, so the accuracy of the galvanometer does not affect the measurement.
- The p.d. measured could be read directly from the circuit through length measurements after the wire is calibrated by using a ______________ cell.
- The driver cell must maintain a ____________ potential difference during all measurements.
- The wire must have a uniform diameter, hence a constant ____________________________.
- The final accuracy of calculation depends on the accuracy with which E_o is known.
- Sliding of jockey along the wire produces ______and may cause a rise in _________ in the wire thus increasing the resistance. Sliding on the wire may cause _______ on it and hence distort the uniformity of its cross-sectional area.
- When a resistor R is connected in series with the driver cell,



$$\frac{E_{XZ}}{V_{XY}} = \frac{l_{XZ}}{l_{XY}}$$

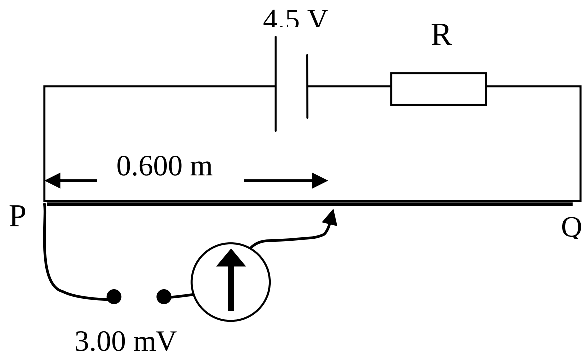
$$V_{XY} = \left(\frac{R_{wire}}{R_{wire} + R}\right) E_{driver}$$

Q1: In the circuit shown above, a standard cell of 2.0 V is connected across RS and the balance length is 22.5 cm. An unknown cell B is then connected across RS and the jockey is now positioned at 15.0 cm from X. What is the e.m.f. of cell B? [1.33V]

Q2: Refer to the circuit above, cell E (driver cell) has a constant e.m.f. of 9 V and negligible internal resistance. Wire XY is 100 cm long and has a resistance of 5 Ω. Resistor R = 10 Ω.

a. The jockey is now positioned at 62.4 cm from Y. What is the e.m.f. of cell B?
b. Cell B has an e.m.f. of 1.5 V. What is length of XZ when the galvanometer shows a zero reading? [1.13V, 50.0 cm]

Q3: The diagram below shows a simple potentiometer circuit for measuring a small e.m.f. produced by a thermocouple.



The meter wire PQ has a resistance of 10 Ω and the driver cell has an e.m.f. of 4.5 V. If a balance point is obtained 0.600 m along PQ when measuring an e.m.f. of 3.00 mV, what is the value of the resistance *R*, in ohms? [8990Ω]