PHY102: LECTURE 13

13.0 Electric current

13.1 Cells and Batteries

A cell can be defined as a chemical device capable of causing electric current to flow. The two main types of cell include Primary cell and secondary cell.

Primary cell: this is a cell in which current is produced as a result of irreversible chemical changes. Example include simple cell, Leclanche cell etc.

Secondary cell: this is cell which can be recharged by passing current backward through it. It only gives out electrical energy stored in it. example include Lead-acid accumulator, alkaline or NiFe accumulator.

13.2 Cells in Series and Parallel

Two or more cells can be connected either in series or in parallel to each other.

A. Series connection of cells: cells are said to be connected in series if the positive terminal of a battery is connected to the negative terminal of another battery. In such arrangement, the total EMF (voltage) is equal to the sum of individual emf of each cell. Similarly, the total internal resistance (r) of the series arrangement is equal to the sum of internal resistance of each cell. Conversely, the same amount of current flows through all the cells in the series arrangement.

Fig. 35.7. Cells in series

B. Parallel arrangement of cells: parallel connection of cells is obtained by connecting all the positive terminals together and all the negative terminals together. The equivalent EMF for any number of equal sources of EMF in parallel is equal to the EMF of one of the cells. The advantage of connecting cells in this way is to lower the internal resistance of the cells and thus supply more current.

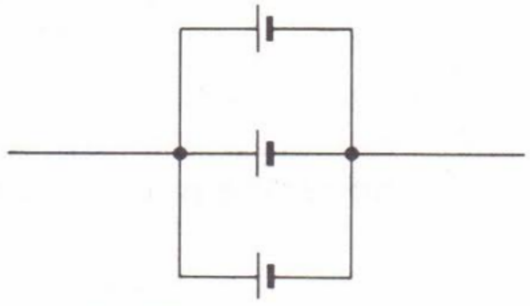


Fig. 35.8. Cells in parallel

13.3 Resistance and Resistor

Resistance can be defined as the opposition offered by a conductor to the flow of charges (current) through it. Its unit is Ohms (Ω).

Ohm's law: states that the current (I) passing through a metallic conductor is proportional to the potential difference (V) across it provided that temperature and other physical conditions remain constant.

i.e $V \propto I$

$$V = RI$$

$$V = IR$$

$$R = \frac{V}{I}$$

Where; R is the resistance of the wire,

Resistor: This is a circuit component designed to have a known resistance. They exist in virtually all electrical devices.

13.4 Factors affecting the resistance of a conductor

Generally, the resistance of a wire depends on the following factors:

i. the length of the wire, L
ii. the cross-sectional area of the wire, A
iii. the resistivity of the wire, ρ
iv. the temperature of the wire. In general, the resistance of a wire increases with increase in temperature.

The first three factors can be connected with the equation below

$$R \propto \frac{L}{A}$$

$$R = \frac{\rho L}{A},$$

$$\rho = \frac{RA}{L}$$

Resistivity is a measure of the extent to which a material can oppose the flow of electric current through it. Its S.I unit is (Ωm).

Example 1: calculate the resistance of 100m length of a wire having a uniform cross-sectional area of $1mm^2$ if the wire is made of manganin having a resistivity of $50\times10^{-8}\Omega m$. (500 Ω)

EXAMple 2: A coil consists of 2000 turns of copper wire having a cross-sectional area of $0.8mm^2$. the mean length per turn is 80cm and resistivy of copper is 0.02μΩm. Find the resistance of the coil.

13.5 Electric Power

Electric power is the rate of energy transfer/consumption in an electrical system. Mathematically,

$$P = VI$$

$$\text{since } V = IR \text{ (from Ohm's law)},$$

$$\Rightarrow P = \frac{V^2}{R} = I^2R$$

The S.I unit of power is watt.

Recall that;

$$\text{power} = \frac{\text{Energy}}{\text{time}}$$

$$\Rightarrow \text{Energy} = P\times t$$

The unit of energy used by electricity distribution companies to calculate electrical consumption is kilowatt-hour (KWh).

1 KWh = $(10^3$ W) (3600 s) = 3.6×10^6 J.

Example: A circuit provides a maximum current of 20.0A at an operating voltage of 1.2×10^2 V. (a) How many 75W bulbs can operate with this voltage source?

(b) At #0.12 per KWh, how much does it cost to operate these bulbs for 8 hours?

13.6 Superconductivity

Superconductivity is a property of complete disappearance of electrical resistance in solids when they are cooled by a characteristic temperature known as critical temperature.

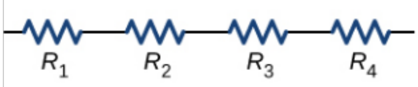
Some Facts about Superconductivity

- Resistivity goes to zero below the critical temperature T_C.
- Many different materials exhibit superconductivity.
- T_C values range from a few mK up to 160K.
- Superconductivity can be destroyed by a critical magnetic field B_C and high current.

14.0 D.C Circuits and Instruments

14.1 Resistors in Series and in Parallel

(a) Series Connection of Resistors: When resistors are connected end to end, they are said to be in series.



(a) Resistors connected in series

Here, same current flows through the resistors because any charge that flows in R1 must also flow in R2 and so on. Conversely, the P.d across each resistor is different. It depends on the resistance of each resistor.

V1 = IR1, V2 = IR2, V3 = IR3, V4 = IR4

$$Vnet = V1 + V2 + V3 + V4$$

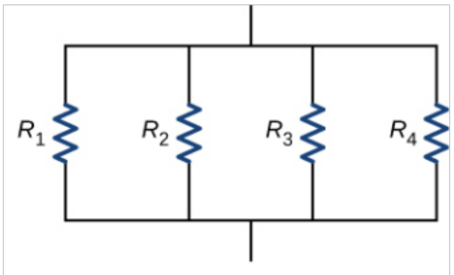
$$= IR1 + IR2 + IR3 + IR4$$

$$= I(R1+R2+R3+R4)$$

The equivalent resistance is the algebraic sum of individual resistance in the connection.

$$Req = R1 + R2 + R3 + R4$$

(b) Parallel Connection of Resistors: this occur when resistors are connected in layers such that all the left sides of the resistors are connected together and the right side connected together.



(b) Resistors connected in parallel

The P.d across each resistor is the same but different current flow through them.

$$I1 = \frac{V}{R1},\ I2 = \frac{V}{R2},\ I3 = \frac{V}{R3},\ \ I4 = \frac{V}{R4}$$

$$Inet = I1 + I2 + I3 + I4$$

$$= \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3} + \frac{V}{R4}$$

$$= V(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4})$$

The reciprocal of the equivalent resistance is the sum of the reciprocal of each resistance in the connection

$$\frac{1}{Req} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4}$$

14.2 Kirchoff's Laws (KCL and KVL)

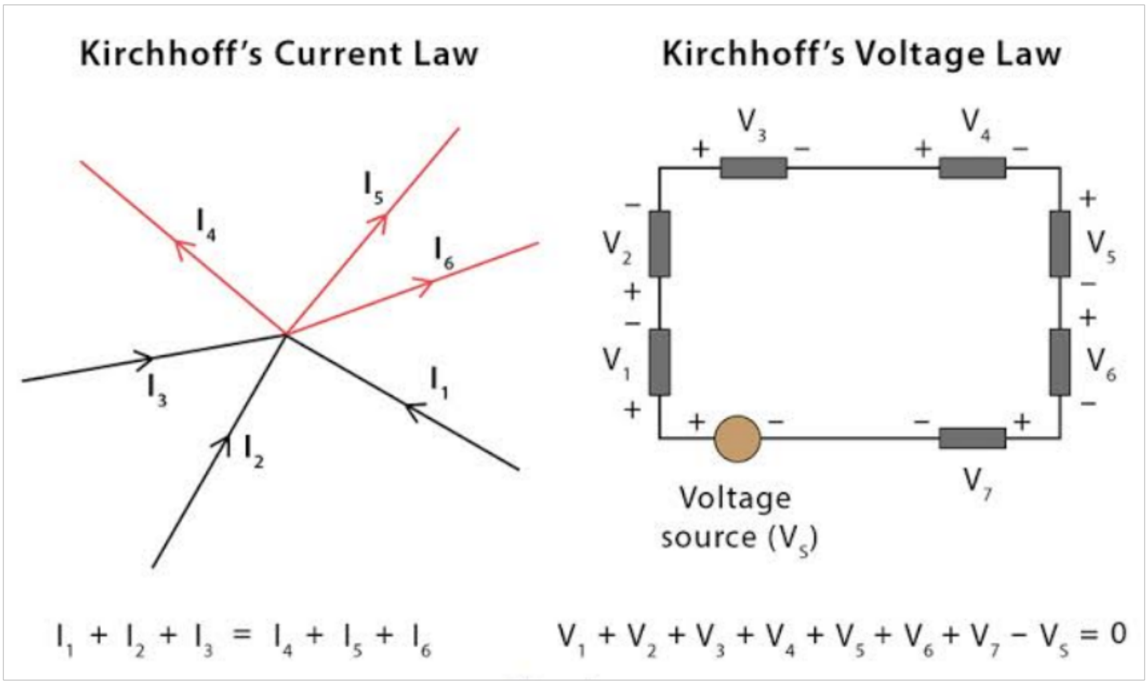
Kirchoff's laws are used to analyse current in a complex circuit.

Junction: a junction in a circuit is a point where three or more conductors meet.

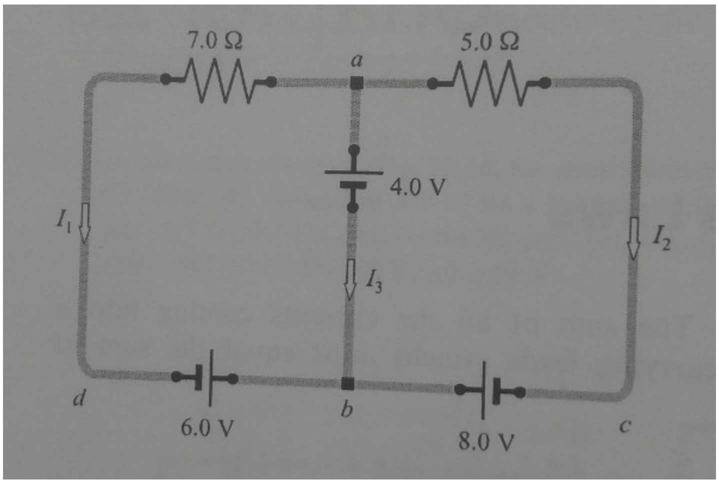
Loop: this is any closed conducting path.

Kirchoff's first law (also known as Kirchoff's current law or junction law): states that the algebraic sum of the current into any junction is zero i.e sum of current flowing towards a junction is equal to sum of the current flowing away from the junction.

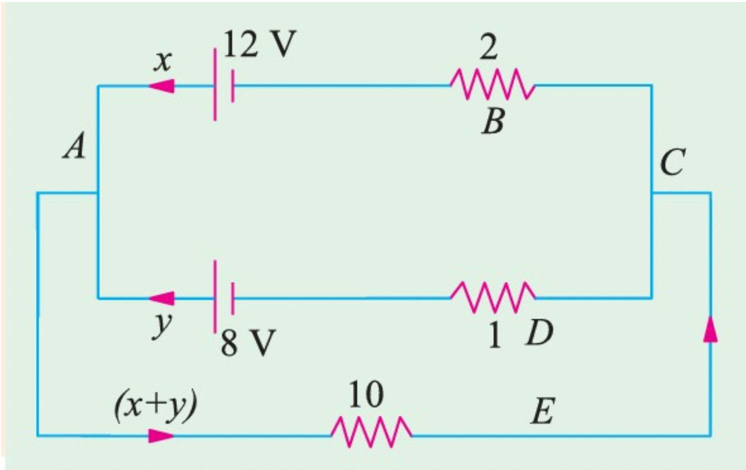
Kirchoff's second law (also known as Kirchoff's voltaget law or loop law): in a closed circuit, the sum of the voltage drops (product of current and resistance of each component of the circuit) taken round a circuit is equal to the E.M.F acting in the circuit. i.e the algebraic sum if the potential difference in any loop must equal zero.



Example 1: ‘calculate the currents I_1, I_2 and I_3 in the circuit below.

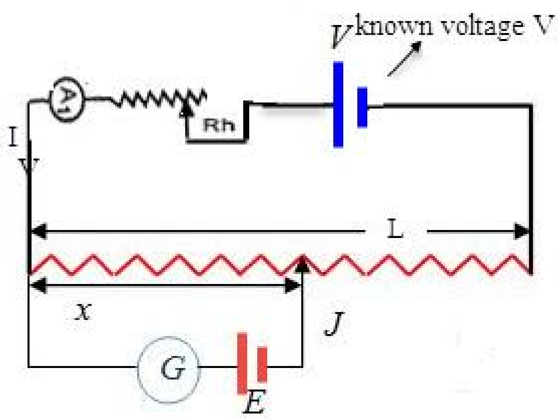


Example2: calculate the currents I_1(x), I_2 (y) and I_3 (x+y) in the circuit below



14.3 The Potentiometer

A potentiometer is a device used for measuring the E.M.F and internal resistance of cells. It can also be used to measure the current in a circuit. It consists of a uniform wire of length L (often fixed on a metre rule). A primary cell with E.M.F V maintains a steady current I in L. Since the wire is uniform, its resistance per centimeter (R) is constant. The P.d between one end of the wire and a point in the middle upon it is thus proportional to the length of the wire X. A secondary circuit which consist of a cell with E.M.F E (to be determined), a galvanometer and a sliding jockey.



A potentiometer can be used to;

i. Compare the E.M.F of two cells.

ii. Determination of internal resistance of a cell.

iii. Measurement of current.

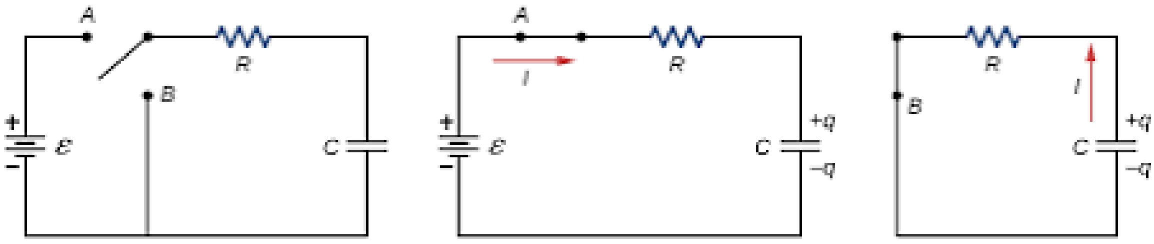
iv. Calibration of voltmeter and ammeter.

v. Compare resistances.

vi. Measurement of thermoelectric E.M.F of a thermocouple.

14.4 RC Circuit

An RC circuit is a circuit which consists of a resistor and a capacitor driven by a voltage source. A capacitor can store energy (by storing charges) while a resistor connected in series with the capacitor controls the rate at which the capacitor charges and discharges. This produces a characteristic time dependence that turns out to be exponential. The parameter that determines the time dependence is the **"time constant"** RC.



(a) Original circuit (b) Charging capacitor (b) Discharging capacitor

In the diagrams above, when the switch is moved to position A, the capacitor charges (circuit b). When the switch is moved to position B, the capacitor discharges through the resistor (circuit C).

The equation when the capacitor is charging is

$$q(t) = CV\left(1\text{-}e^{-t/RC}\right) = Q\left(1\text{-}e^{-t/RC}\right), \qquad \text{since } Q = CV$$

$$I(t) = \frac{dq(t)}{dt} = \frac{d\left[CV\left(1\text{-}e^{-t/RC}\right)\right]}{dt}$$

$$\Rightarrow I(t) = \frac{V}{R}e^{-t/RC} = \frac{Q}{RC}e^{-t/RC}$$

The equation when the capacitor is discharging is

$$q(t) = CVe^{-t/RC} = Qe^{-t/RC}$$

$$I(t) = \frac{dq(t)}{dt} = \frac{d\left(CVe^{-t/RC}\right)}{dt}$$

$$\Rightarrow I(t) = \frac{-V}{R}e^{-t/RC} = \frac{-Q}{RC}e^{-t/RC}$$

Application of RC Circuits

They are used as timers in windshield wipers, traffic light etc.

They are used in audio equipment.

They can be used as filter.

14.5 Electrostatic Voltmemter

This is an instrument which can be used to measure the P.d in charged conductors. It uses the fact that charge is a function of voltage and instrument capacitance. Electrostatic instruments generally function by measuring the mechanical displacement caused by the deflecting torques produced by electric fields on charged conductors. Types of electrostatic voltmeter are repulsion, attraction and symmetrical type voltmeter.

14.6 Cathode Ray Oscilloscope (CRO)

A cathode ray oscilloscope is a device that measures potential differences and how they vary over time. It is typically used to measure the period and peak P.d of repeated waveforms and to determine the shape of the waveforms.

Uses of CRO

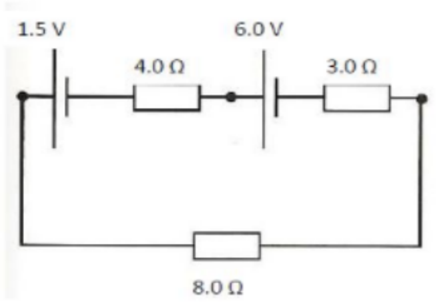
- Display waveforms of alternating voltage.
- Measure potential difference (both D.C and A.C)
- Measurement of frequency
- Measurement of phase.

14.7 Digital Voltmeter

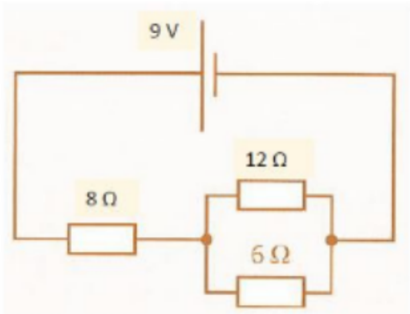
A digital voltmeter is a voltage sensitive device which measures A.C or D.C voltage and displays the value in the numeric form instead of pointer deflection. The accuracy of a digital voltmeter can be affected by the temperature input impedance, variation in power supply voltage.

Practice Questions.

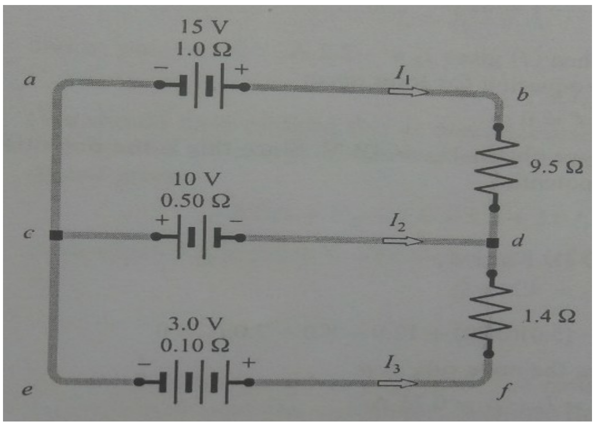
1. In the circuit shown below calculate the current flowing and the pd across the 8 ohm resistor.



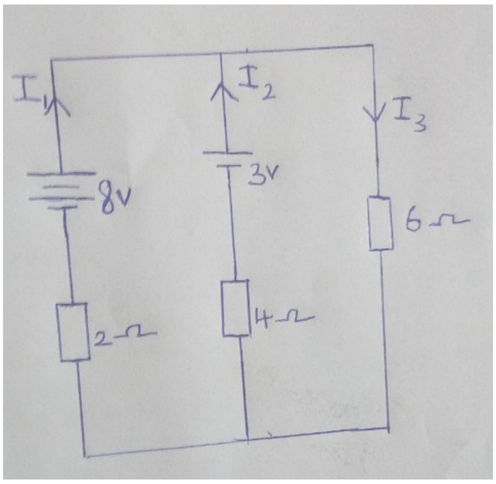
2. Calculate the potential difference across and the current through the 6 ohm resistor in the circuit below.



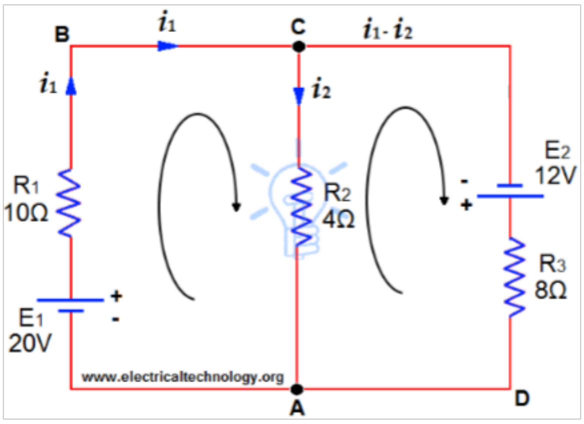
3. Calculate the currents I_1, I_2 and I_3 and the potential difference between point b and e in the circuit below



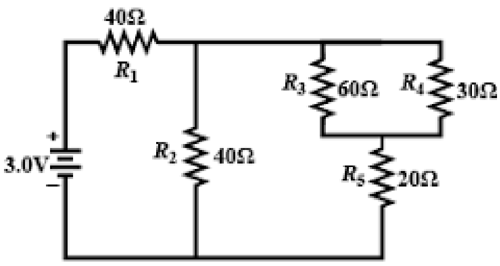
4. Calculate the currents I_1, I_2 and I_3 and the potential terminal voltage in the circuit below

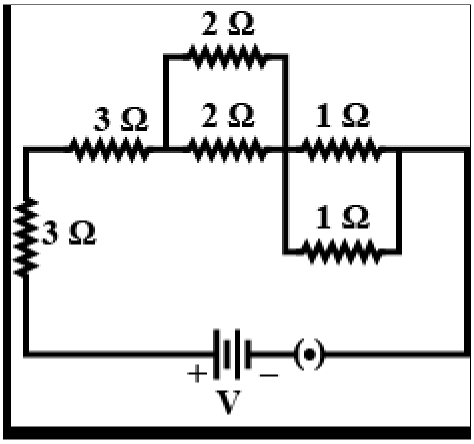


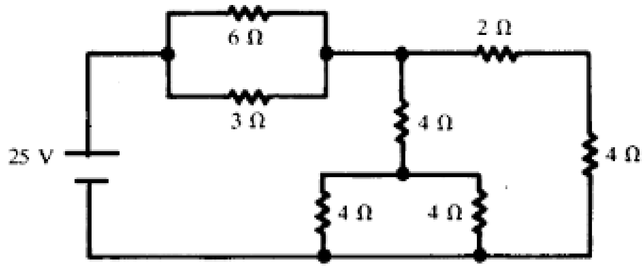
5. Calculate the currents I_1, I_2 and $I_3(I_1 - I_2)$ in the circuit below

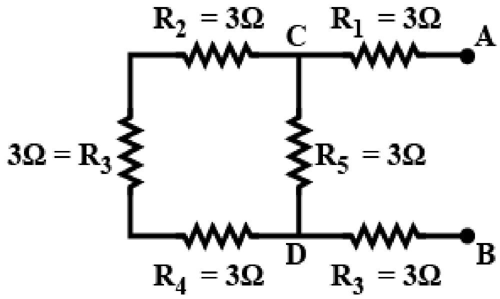


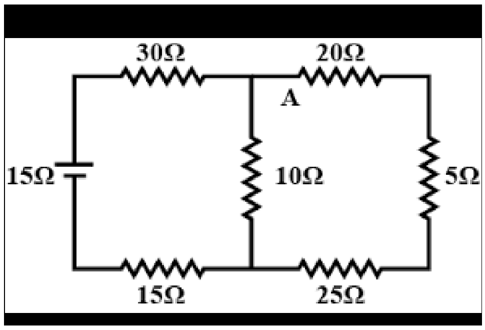
6. Calculate the equivalence resistance in the circuits below











7. A wire is made of aluminium has a diameter of 2.59mm, how many meters of wire are needed to give a resistance of 10 Ω? Resistivity for aluminium is 2.8×10^{-8}Ωm.

8. A metal rod is 200cm long and 8mm in diameter. Compute its resistance if the resistivity is 1.76×10^{-8}Ωm.

9. It is desired to make a wire that has a resistance of 8.0 Ω from $5.0cm^3$ of metal with a resistivity of 9.0×10^{-8}Ωm. What should be the length and cross-sectional area of the wire?

10. An electric iron of resistance 20 Ω takes a current of 5.0A. Calculate the thermal energy, in joules, developed in 30s.

11. The lights of a car are inadvertently left on. They dissipate 95.0W. About how long will it take for the fully charged 12.0V car battery to run down if the battery is rated 150 ampere-hour?

12. An electric motor takes 15.0A at 10V. determine (a)the power input (b)the cost of operating the motor for 8hrs at #0.50/KWh.