University of Science and Technology

Faculty of Computer Science and Information Technology

Course Handbook

Physics II

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Lecture three

Current, Resistance, and Ohm’s Law

Current, Resistance, and Ohm's Law

A CURRENT (I) of electricity exists in a region when a net electric charge is transported from one point to another in that region. Suppose the charge is moving through a wire. If a charge q is transported through a given cross section of the wire in a time t, then the current through the wire is

$$I = \frac{q}{t}$$

Here, q is in coulombs, t is in seconds, and I is in *amperes* (1 A = 1 C/s). By custom the direction of the current is taken to be in the direction of flow of positive charge. Thus, a flow of electrons to the right corresponds to a current to the left.

A BATTERY is a source of electrical energy. If no internal energy losses occur in the battery, then the potential difference (see Chapter 25) between its terminals is called the *electromotive force* (emf) of the battery. Unless otherwise stated, it will be assumed that the terminal potential difference of a battery is equal to its emf. The unit for emf is the same as the unit for potential difference, the volt.

THE RESISTANCE (R) of a wire or other object is a measure of the potential difference (V) that must be impressed across the object to cause a current of one ampere to flow through it:

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

The unit of resistance is the *ohm*, for which the symbol Ω (Greek omega) is used. $1\ \Omega = 1\ \mathrm{V/A}$.

OHM'S LAW originally contained two parts. Its first part was simply the defining equation for resistance, $V = IR$. We often refer to this equation as being Ohm's Law. However, Ohm also stated that R is a constant independent of V and I. This latter part of the Law is only approximately correct.

The relation $V = IR$ can be applied to any resistor, where V is the potential difference (p.d.) between the two ends of the resistor, I is the current through the resistor, and R is the resistance of the resistor under those conditions.

MEASUREMENT OF RESISTANCE BY AMMETER AND VOLTMETER: A series circuit consisting of the resistance to be measured, an ammeter, and a battery is used. The current is measured by the (low-resistance) ammeter. The potential difference is measured by connecting the terminals of a (high-resistance) voltmeter across the resistance, i.e., in parallel with it. The resistance is computed by dividing the voltmeter reading by the ammeter reading according to Ohm's Law, $R = V/I$. (If the exact value of the resistance is required, the resistances of the voltmeter and ammeter must be considered parts of the circuit.)

THE TERMINAL POTENTIAL DIFFERENCE (or *voltage*) of a battery or generator when it delivers a current I is related to its electromotive force e and its *internal resistance* r as follows:

(1) When delivering current (*on discharge*):

$$\text{Terminal voltage} = (\text{emf}) - (\text{voltage drop in internal resistance})$$
$$V = \mathscr{E} - Ir$$

(2) When receiving current (*on charge*):

$$\text{Terminal voltage} = \text{emf} + (\text{voltage drop in internal resistance})$$
$$V = \mathscr{E} + Ir$$

(3) When no current exists:

$$\text{Terminal voltage} = \text{emf of battery or generator}$$

RESISTIVITY: The resistance R of a wire of length L and cross-sectional area A is

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

where ρ is a constant called the *resistivity*. The resistivity is a characteristic of the material from which the wire is made. For L in m, A in m^2, and R in Ω, the units of ρ are $\Omega \cdot m$.

RESISTANCE VARIES WITH TEMPERATURE: If a wire has a resistance R_0 at a temperature T_0, then its resistance R at a temperature T is

$$R = R_0 + \alpha R_0(T - T_0)$$

where α is the *temperature coefficient of resistance* of the material of the wire. Usually α varies with temperature and so this relation is applicable only over a small temperature range. The units of α are K^{-1} or $^{\circ}C^{-1}$.

A similar relation applies to the variation of resistivity with temperature. If ρ_0 and ρ are the resistivities at T_0 and T, respectively, then

$$\rho = \rho_0 + \alpha\rho_0(T - T_0)$$

POTENTIAL CHANGES: The potential difference across a resistor R through which a current I flows is, by Ohm's Law, IR. The end of the resistor at which the current enters is the high-potential end of the resistor. Current always flows "downhill," from high to low potential, through a resistor.

The positive terminal of a battery is always the high-potential terminal if internal resistance of the battery is negligible or small. This is true irrespective of the direction of the current through the battery.

Solved Problems

A steady current of 0.50 A flows through a wire. How much charge passes through the wire in one minute?

Because $I = q/t$, we have $q = It = (0.50\ \text{A})(60\ \text{s}) = 30\ \text{C}$. (Recall that $1\ \text{A} = 1\ \text{C/s}$.)

How many electrons flow through a light bulb each second if the current through the light bulb is 0.75 A?

From $I = q/t$, the charge flowing through the bulb in 1.0 s is

$$q = It = (0.75\ \text{A})(1.0\ \text{s}) = 0.75\ \text{C}$$

But the magnitude of the charge on each electron is $e = 1.6 \times 10^{-19}$ C. Therefore,

$$\text{Number} = \frac{\text{charge}}{\text{charge/electron}} = \frac{0.75\ \text{C}}{1.6 \times 10^{-19}\ \text{C}} = 4.7 \times 10^{18}$$

A light bulb has a resistance of $240\,\Omega$ when lit. How much current will flow through it when it is connected across 120 V, its normal operating voltage?

$$I = \frac{V}{R} = \frac{120\ \text{V}}{240\ \Omega} = 0.500\ \text{A}$$

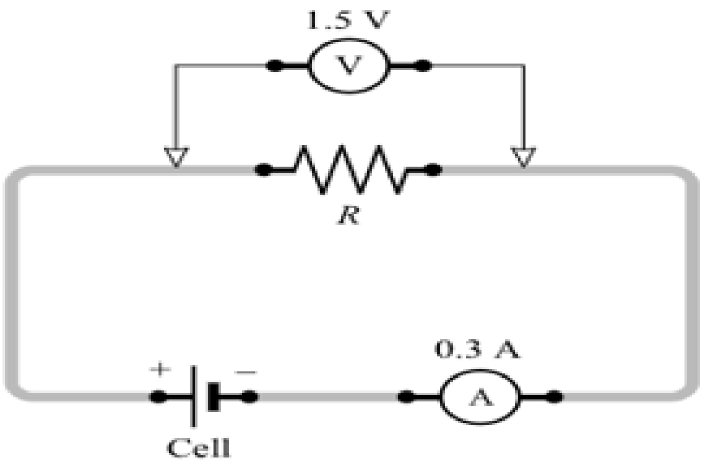
An electric heater uses 5.0 A when connected across 110 V. Determine its resistance.

$$R = \frac{V}{I} = \frac{110\ \mathrm{V}}{5.0\ \mathrm{A}} = 22\ \Omega$$

What is the potential drop across an electric hot plate that draws 5.0 A when its hot resistance is 24 Ω?

$$V = IR = (5.0\ \mathrm{A})(24\ \Omega) = 0.12\ \mathrm{kV}$$

As shown in Fig. 26-4 the ammeter–voltmeter method is used to measure an unknown resistance *R*. The ammeter reads 0.3 A, and the voltmeter reads 1.50 V. Compute the value of *R* if the ammeter and voltmeter are ideal.



$$R = \frac{V}{I} = \frac{1.50\ \mathrm{V}}{0.3\ \mathrm{A}} = 5\ \Omega$$

A metal rod is 2 m long and 8 mm in diameter. Compute its resistance if the resistivity of the metal is $1.76 \times 10^{-8}\ \Omega \cdot \mathrm{m}$.

$$R = \rho \frac{L}{A} = (1.76 \times 10^{-8}\ \Omega \cdot \mathrm{m}) \frac{2\ \mathrm{m}}{\pi(4 \times 10^{-3}\ \mathrm{m})^2} = 7 \times 10^{-4}\ \Omega$$

Number 10 wire has a diameter of 2.59 mm. How many meters of number 10 aluminum wire are needed to give a resistance of 1.0 Ω? ρ for aluminum is $2.8 \times 10^{-8}\ \Omega \cdot \mathrm{m}$.

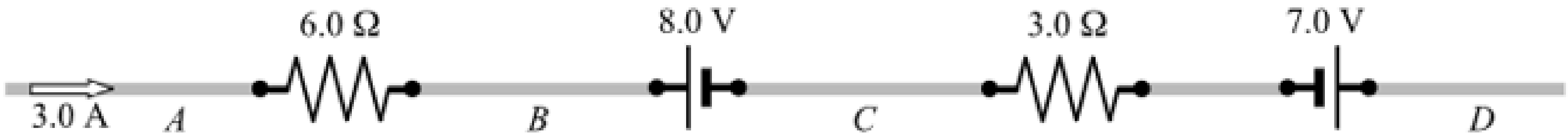
From $R = \rho L/A$, we have

$$L = \frac{RA}{\rho} = \frac{(1.0\ \Omega)(\pi)(2.59 \times 10^{-3}\ \mathrm{m})^2/4}{2.8 \times 10^{-8}\ \Omega \cdot \mathrm{m}} = 0.19\ \mathrm{km}$$

The resistance of a coil of copper wire is 3.35 Ω at 0 °C. What is its resistance at 50 °C? For copper, $\alpha = 4.3 \times 10^{-3}\,°\mathrm{C}^{-1}$.

$$R = R_0 + \alpha R_0(T - T_0) = 3.35\ \Omega + (4.3 \times 10^{-3}\,°\mathrm{C}^{-1})(3.35\ \Omega)(50\,°\mathrm{C}) = 4.1\ \Omega$$

A current of 3.0 A flows through the wire shown in Fig. 26-2. What will a voltmeter read when connected from (*a*) *A* to *B*, (*b*) *A* to *C*, (*c*) *a* to *D*?

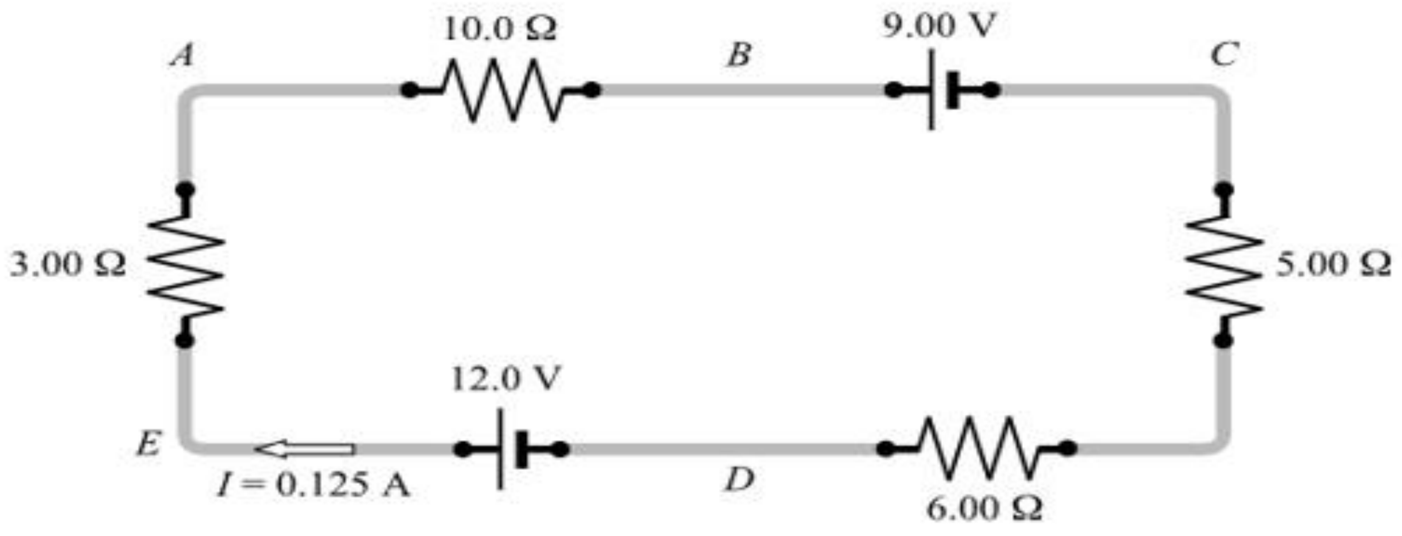


(*a*) $V_{AB} = +(3.0)(6.0) = +18$ V; *B* is higher.

(*b*) $V_{AC} = +(3.0)(6.0) - 8.0 = +10$ V; *C* is higher.

(*c*) $V_{AD} = +(3.0)(6.0) - 8.0 + (3.0)(3.0) + 7.0 = +26$ V; *D* is higher.

The current in Fig. 26-1 is 0.125 A in the direction shown. For each of the following pairs of points, what is their potential difference, and which point is at the higher potential? (*a*) *A*, *B*; (*b*) *B*, *C*; (*c*) *C*, *D*; (*d*) *D*, *E*; (*e*) *C*, *E*; (*f*) *E*, *C*.



(*a*) $V_{AB} = -IR = -(0.125\text{ A})(10.1\ \Omega) = -1.25\text{ V}$; *A* is higher.

(*b*) $V_{BC} = -\mathscr{E} = -9.00\text{ V}$; *B* is higher.

(*c*) $V_{CD} = -(0.125\text{ A})(5.00\ \Omega) - (0.125\text{ A})(6.00\ \Omega) = -1.38\text{ V}$; *C* is higher.

(*d*) $V_{DE} = +\mathscr{E} = +12.0\text{ V}$; *E* is higher.

(*e*) $V_{CE} = -(0.125\text{ A})(5.00\ \Omega) - (0.125\text{ A})(6.00\ \Omega) + 12.0\text{ V} = +10.6\text{ V}$; *E* is higher.

(*f*) $V_{EC} = -(0.125\text{ A})(3.00\ \Omega) - (0.125\text{ A})(10.0\ \Omega) - 9.00\text{ V} = -10.6\text{ V}$; *E* is higher.

Supplementary Problems

How many electrons per second pass through a section of wire carrying a current of 0.70 A?
Ans. 4.4×10^{18} electrons/s

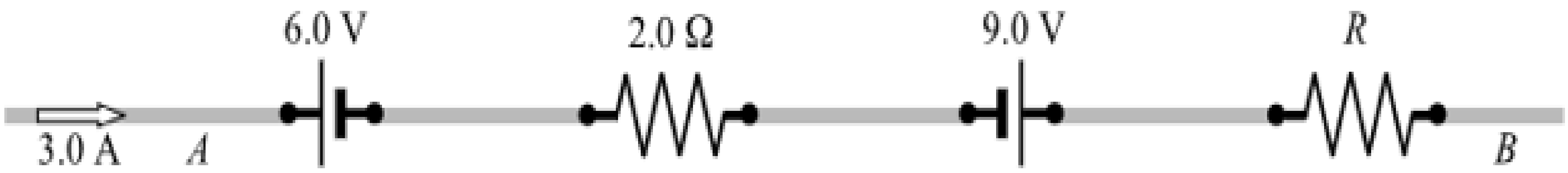
An electron gun in a TV set shoots out a beam of electrons. The beam current is 1.0×10^{-5} A. How many electrons strike the TV screen each second? How much charge strikes the screen in a minute?
Ans. 6.3×10^{13} electrons/s, -6.0×10^{-4} C/min

What is the current through an 8.0-Ω toaster when it is operating on 120 V? *Ans.* 15 A

What potential difference is required to pass 3.0 A through 28 Ω? *Ans.* 84 V

Determine the potential difference between the ends of a wire of resistance 5.0 Ω if 720 C passes through it per minute. *Ans.* 60 V

Find the potential difference between points A and B in Fig. 26-5 if R is 0.70 Ω. Which point is at the higher potential? *Ans.* −5.1 V, point A



Compute the resistance of 180 m of silver wire having a cross-section of 0.30 mm^2. The resistivity of silver is $1.6 \times 10^{-8}\ \Omega \cdot m$. *Ans.* 9.6 Ω

A coil of wire has a resistance of 25.00 Ω at 20 °C and a resistance of 25.17 Ω at 35 °C. What is its temperature coefficient of resistance? *Ans.* $4.5 \times 10^{-4}\ °C^{-1}$