

Time Allowed: 2 hours

Total points: 100

Some Physics Constants:	electronic charge	$e = 1.6 \times 10^{-19} \text{ C}$
	Coulomb constant	$k = 9.0 \times 10^9 \text{ Nm}^2/\text{C}^2$
	Permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$
	Mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
	Mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$

A Yes/No questions (Total points=10. Points per question=2)

1. Electric field lines lie on equipotential surfaces.

Yes

No

2. When a negative point charge moves from a position of low electric potential to one of high potential, the work done by the electric field is positive.

Yes

No

3. The electric potential is nowhere equal to zero for an electric dipole except at infinity.

Yes

No

4. When a dielectric material is withdrawn between the charged plates of a parallel plate capacitor with the plates isolated from each other, the potential difference is reduced.

Yes

No

$$\overset{\leftarrow}{Q} = \underset{\uparrow}{C} \underset{\downarrow}{V}$$

5. The electrical resistance of a 100W light bulb is smaller than that of a 60W light bulb.

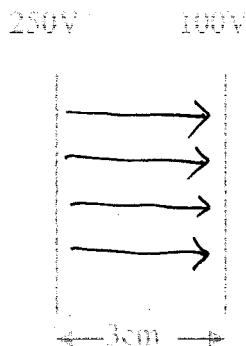
Yes

No

$$R = \frac{V^2}{P} = \frac{120^2}{P} \propto \frac{1}{P}$$

B Multiple Choice Questions (Total points =60 points. Points per question = 5)

The next three questions refer to the following diagram showing two planar equipotential surfaces. The potential on the right plane is 100V and that on the left plane is 250V. They are 3.0 cm apart.



6. Calculate the electric field between the surfaces and draw a number of field lines on the diagram.

- (a) 2000 N/C
- (b) 2500 N/C
- (c) 5000 N/C
- (d) 7500 N/C

$$|E| = \frac{|\Delta V|}{|\Delta x|} = \frac{250 - 100}{0.03} \text{ V/m} = 5000 \text{ N/C}$$

7. If a bare nucleus of ${}_5B^{10}$ is released at rest from the left plane, what is its kinetic energy when it arrives at the right plane?

- (a) 750 eV
- (b) 1000 eV
- (c) 1500 eV
- (d) 2000 eV

$$\Delta K = W$$

$$K_f - K_i = q(V_i - V_f)$$

$$K_i = 0 \quad q = 5e \quad V_i - V_f = 250 - 100 = 150 \text{ V}$$

$$\therefore K_f = 5e \times 150 \text{ J} = 750 \text{ eV}$$

8. What is the velocity of the boron nucleus at that time?

- (a) $1.7 \times 10^5 \text{ m/s}$
- (b) $1.2 \times 10^5 \text{ m/s}$
- (c) $8.5 \times 10^4 \text{ m/s}$
- (d) $6.3 \times 10^4 \text{ m/s}$

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2 \times 750 \times 1.6 \times 10^{-19}}{10 \times 1.67 \times 10^{-27}}} = 1.2 \times 10^5 \text{ m/s}$$

9. In a region where there is electric field, a negative charge of 5nC is found to experience an increase of kinetic energy of 20nJ in going from point A to point B under the influence of the electric field alone. If the electric potential at A is 10V, what is its value at B?

- (a) 14V
- (b) 10V
- (c) 6V
- (d) 2V

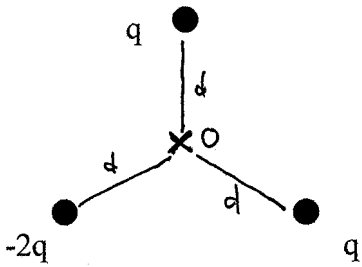
$$\Delta K = q(V_A - V_B)$$

$$20 \times 10^{-9} = -5 \times 10^{-9} (V_A - V_B)$$

$$V_A - V_B = -4$$

$$V_B = V_A + 4 = 14$$

10. Three point charges $q, q, -2q$ are situated at the vertices of an equilateral triangle as shown. Identify on the diagram (if exists) a point where the electric potential is zero and give reason for the choice.



$$V_0 = k \frac{(-2q)}{d} + k \frac{q}{d} + k \frac{q}{d} = 0$$

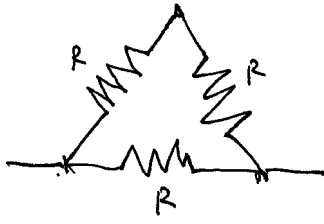
11. The life-time of a battery is 2800 A-hr (ampere-hour). The emf of the battery is 6.0V. Assuming it is an ideal battery, what is the total energy it can deliver in its life time?

- (a) 70 MJ
- (b) 60 MJ
- (c) 50 MJ
- (d) 40 MJ

Total charge $Q = 2800 \times 3600 = 1.0 \times 10^7 \text{ C}$
 Energy delivered $QE = 1.0 \times 10^7 \times 6 = 6 \times 10^7 \text{ J}$

12. Three identical resistances R are connected to form a triangle. What is the resistance between any two vertices?

- (a) $R/3$
- (b) $2R/3$
- (c) $3R/2$
- (d) $3R$



$$= \text{Circuit diagram showing } 2R \text{ in parallel with } R \text{ in parallel with } R \text{ in parallel with } R$$

$$\text{Reg} = \frac{(2R)R}{2R+R} = \frac{2R}{3}$$

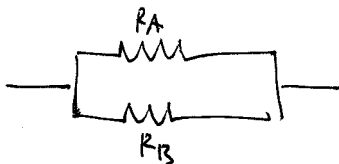
13. The resistance of a certain light bulb is 200Ω . If it is used by connecting to a wall outlet of 120V, and if the cost of electricity is \$0.05 per kWh, what is the total cost if it is lit up continuously for a week?

- (a) \$1.60
- (b) \$1.20
- (c) \$0.80
- (d) \$0.60

Power consumed $P = \frac{V^2}{R} = \frac{120^2}{200} = 72 \text{ W} = 72 \times 10^{-3} \text{ kW}$
 Total energy consumed $= 72 \times 7 \times 24 \times (72 \times 10^{-3}) \times (7 \times 24)$
 $= 12.1 \text{ kWh}$
 Cost $= \$0.05 \times 12.1 = \0.60

14. Two resistors A and B are connected in parallel. The resistances, voltages, and currents in each are denoted by $R_A, R_B, V_A, V_B, I_A, I_B$. Given that $R_A > R_B$ which of the following statement is correct?

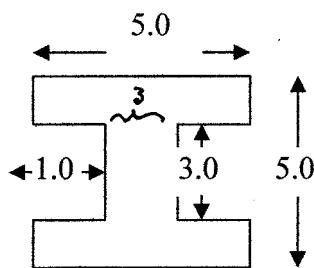
- (a) $V_A > V_B$ $I_A < I_B$
 (b) $V_A > V_B$ $I_A > I_B$
 (c) $V_A = V_B$ $I_A < I_B$
 (d) $V_A = V_B$ $I_A > I_B$



15. Which of the following statements concerning the emf of a battery is **incorrect**?

- (a) It cannot be less than the terminal voltage when connected to a load resistance.
 (b) It is a quantity occurring in Ohm's law.
 (c) It can be measured directly with a voltmeter.
 (d) It is equal to the energy delivered when one Coulomb of charge flows through it.

16. The diagram below shows the cross-section of a railroad track with dimensions in cm. The cross-section is updown and left-right symmetric. It is made from steel for which the resistivity is $9.7 \times 10^{-8} \Omega \cdot m$. How long must be the track so that its electrical resistance is 10Ω ?



- (a) 100 km
 (b) 200 km
 (c) 300 km
 (d) 400 km

Cross-sectional area $A = 2 \times 5 \times 1 + 3 \times 3$
 $= 19 \text{ cm}^2 = 19 \times 10^{-4} \text{ m}^2$

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

$L = \frac{RA}{\rho} = \frac{10 \times 19 \times 10^{-4}}{9.7 \times 10^{-8}} = 1.96 \times 10^5 \text{ m}$
 $\approx 200 \text{ km}$

17. The emf of a battery is 2.4 V . When it is connected to a load resistance of 8.0Ω , the terminal voltage is only 1.6 V . Find the current in the load and the internal resistance of the battery.

- (a) 0.4 A 2.0Ω
 (b) 0.4 A 4.0Ω
 (c) 0.2 A 2.0Ω
 (d) 0.2 A 4.0Ω

$I = \frac{V}{R} = \frac{1.6}{8} = 0.2 \text{ A}$

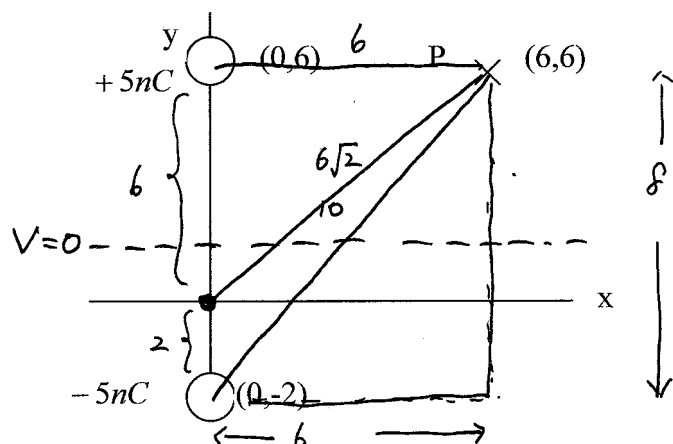
$\mathcal{E} = I(R+r)$

$R+r = \frac{\mathcal{E}}{I} = \frac{2.4}{0.2} = 12$

$r = 12 - R = 4 \Omega$

C Multi-step problems (Total points=30)

18. The figure below shows an electric dipole of point charges -5nC and $+5\text{nC}$, located at the points $(0,-2)$ and $(0,6)$ respectively, where the coordinates are in meters. The point P has coordinates $(6,6)$.



- (a) Determine the electric potentials at the point P and at the origin. (5 points)

$$V_P = V_T + V_B = 9 \times 10^9 \times \frac{5 \times 10^{-9}}{6} + 9 \times 10^9 \times \frac{-5 \times 10^{-9}}{10} = 7.5 - 4.5 = 3.0 \text{ V}$$

$$V_0 = 9 \times 10^9 \times \frac{5 \times 10^{-9}}{6} + 9 \times 10^9 \times \frac{-5 \times 10^{-9}}{2} = 7.5 - 22.5 = -15 \text{ V}$$

- (b) If an electron is moved by an external force from the origin to P in such a way that its velocity remains small, what is the work done by this force? (3 points)

$$0 = \Delta K = W_{\text{ext}} + W_E$$

$$W_{\text{ext}} = -W_E = -q(V_0 - V_P) = 1.6 \times 10^{-19} \times (-15 - 3) = -2.9 \times 10^{-18} \text{ J}$$

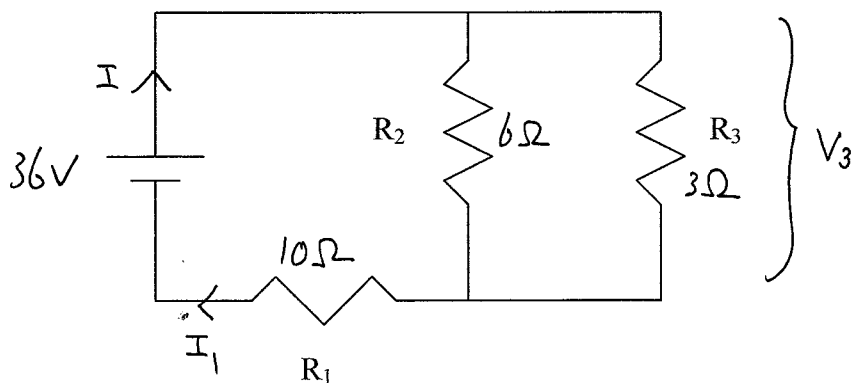
- (c) Sketch on the figure a line where the electric potential is zero. (2 points) *dotted line*

- (d) If an additional point charge q is placed at the origin so that the potential at P is reduced to zero, what is the magnitude and sign of q ? (5 points)

$$9 \times 10^9 \times \frac{q}{6\sqrt{2}} + 3 = 0 \quad \leftarrow \text{from (a)}$$

$$q = -\frac{3 \times 6\sqrt{2}}{9} \times 10^{-9} \text{ C} = -2\sqrt{2} \text{ nC} = -2.8 \text{ nC}$$

19. In the circuit below, the values of the resistances are given by $R_1 = 10\Omega$ $R_2 = 6\Omega$ $R_3 = 3\Omega$ and the emf of the ideal battery is $36V$.



(1) (5 points) Find the current going through R_1 .

$$R_{eq} = 10 + \frac{6 \times 3}{6 + 3} = 12 \Omega$$

$$I = \frac{\mathcal{E}}{R_{eq}} = \frac{36}{12} = 3 \text{ A} = I_1$$

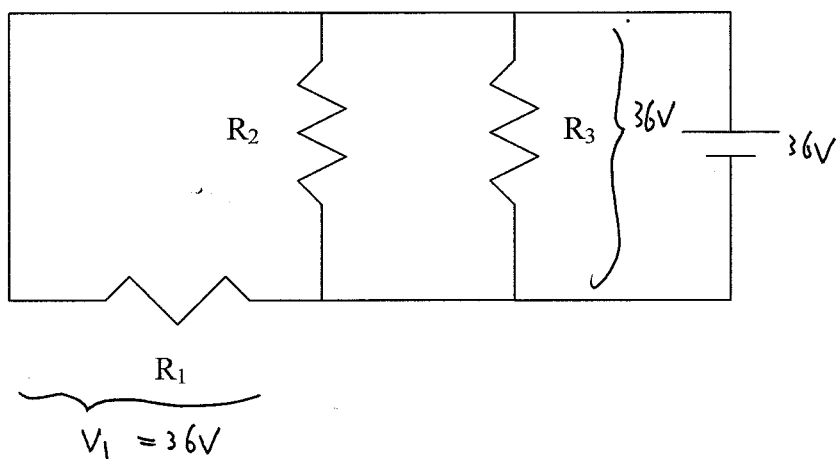
(2) (5 points) Find the voltage across R_3 and the power dissipated in it.

$$V_1 = I_1 R_1 = 3 \times 10 = 30 \text{ V}$$

$$V_3 = 36 - 30 = 6 \text{ V}$$

$$P_3 = \frac{V_3^2}{R_3} = \frac{6^2}{3} = 12 \text{ W}$$

(3) (5 points) If the battery is switched over to the other side as shown, does the current through R_1 change? If so, what is its new value?



Yes.

$$V_3 = 36 \text{ V}$$

$$I_1 = \frac{36}{10} = 3.6 \text{ A}$$