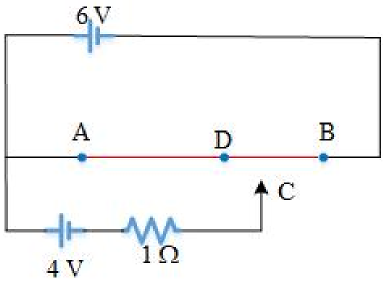
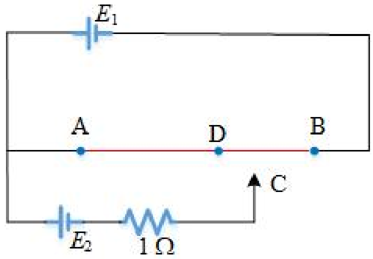
Electromagnetism: Effect of Current Electricity– Typical Questions (Set 2)

(Representative Questions with Answers & Illustrations)

Q-1	A 6 volt battery of negligible internal resistance is connected across a uniform wire AB of length 100 cm. The positive terminal of the battery of emf 4 V and internal resistance 1 Ω is joined to end A as shown in the figure. Take the potential at B to be zero.  (a) What are the potentials at the points A and C? (b) At which point D of the wire AB, the potential is equal to potential at C? (c) If the points C and D are connected by a wire, what will be the current through it? (d) If 4 V battery is replaced by 7.5 battery what would be the answer of parts (a) and (b)
A-1	(a) 6 V, 2 V (b) AD = 66.7 cm (c) Zero (d) 6 V, -1.5 V no such point D exists
I-1	This problem though looks similar to that on Wheatstone Bridge, it has some deviation from it. Let wire AB of length $L = 100$ cm has uniform resistance ρ Ω/cm. Let, distance AD is x cm corresponding to $R_1 = x$ Ω the distance DB be $(L - x)$ cm corresponding to $R_2 = (L - x)$ Ω. Solving each part separately –  **Part (a):** Negative terminal is directly connected, without any resistance, to end B of the wire and the end is stated to be at potential Zero. Likewise, positive terminal of the battery with $E_1 = 6$ V is directly connected to end A of the wire. Hence, as per *Kirchhoff's Circuital Law* potential at A will be $V_A = V_B + E_1 \Rightarrow 0 + (+6) \Rightarrow \boldsymbol{V_A = 6}$ **V**. As regards potential at C, which is floating, it is connected to A through a resistance $r = 1$ Ω and a battery having $E_2 = 4$ volts connected with reverse polarity.; the link carries no current $i = 0$. Therefore, $V_C = V_A - (E_2 + ir) \Rightarrow V_C = 6 - (4 + 0 \times 1) \Rightarrow \boldsymbol{V_C = 2}$ **V**. **Part (b):** The emf E_1 uniformly is spread out along wire AB such that potential gradient along the wire AB is $\delta = \frac{\Delta V}{\Delta l} = \frac{V_B - V_A}{L} = \frac{0-6}{100} \Rightarrow \delta = -0.06$ V/cm. For $V_D = V_c = 2$ V, distance x of point D on the wire say from end A is $V_D - V_A = x \times \delta \Rightarrow x = \frac{V_D - V_A}{\delta}$. Using the available data $x = \frac{2-6}{-0.06} \Rightarrow \boldsymbol{x = 66.7}$ **cm.** **Part (c):** Point C and point D determined at part (b) if connected by wire, resistance of which is say r' then current through wire would be D, $i = \frac{V_D - V_C}{r'}$. Using the available data, $i = \frac{2-2}{r'} = \frac{0}{r'} \Rightarrow \boldsymbol{i = 0}$ **Part (d):** Given that battery is changed such that $E_2 = 7.5$ V, with given set of connection resolving the three parts – **(i)** $V_A = V_B + E_1 \Rightarrow 0 + (+6) \Rightarrow \boldsymbol{V_A = 6}$ **V;** **(ii)** $V_C = V_A - (E_2 + ir) \Rightarrow V_C = 6 - (7.5 + 0 \times 1) \Rightarrow \boldsymbol{V_C = -1.5}$**V** **(iii)** $x = \frac{-1.5-6}{-0.06} = 125$ cm it turns out to be outside the wire, while point D is shown to be between A and B. Thus, **no such point exits** Thus, **answers are (a) 6 V, 2 V (b) AD = 66.7 cm (c) Zero (d) 6 V, -1.5 V no such point D exists**

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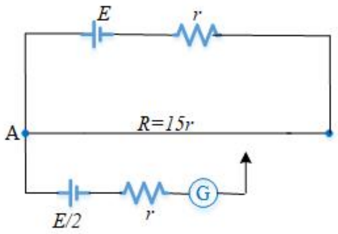
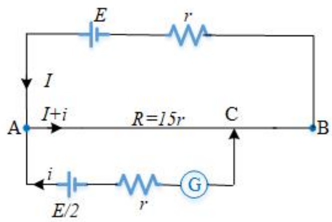
<tr><td></td><td>N.B.: This problem can be structured into objection question on each part. But a full length questions needs to be solved in a stepwise manner.</td></tr>
<tr><td>Q-2</td><td>Consider the potentiometer circuit arranged in figure. The potentiometer wire is 600 cm long.
(a) At what distance from the point A should jockey touch the wire to get zero deflection in galvanometer?
(b) If the jockey touches the wire at a distance of 560 cm from A, what will be the current in the galvanometer?

</td></tr>
<tr><td>A-2</td><td>(a) 320 cm (b) $\frac{3E}{22r}$</td></tr>
<tr><td>I-2</td><td>Resistance per unit length of a potentiometer wire AB of length $L = 600$ cm and resistance $R = 15r$ is $\rho = \frac{R}{L} = \frac{15r}{600} \Rightarrow \rho = \frac{r}{40}$. Each part is solved separately as under


Part (a): Let jockey at a point C at distance x from A shows zero deflection of the galvanometer i.e. $i = 0$. Therefore, circuit current $I = \frac{E}{r+R} = \frac{E}{r+15r} \Rightarrow I = \frac{E}{16r}$. Therefore, potential gradient along the wire would be $\delta = -I\rho = -\frac{E}{16r} \times \frac{r}{40} \Rightarrow \delta = -\frac{E}{640}$ V/cm. Since, there is no current through the branch having galvanometer hence potential at C is $V_C = \frac{E}{2}$. As regards along the wire $V_C - V_A = x\delta \Rightarrow V_C = V_A + x\delta \Rightarrow \frac{E}{2} = E + x\left(-\frac{E}{640}\right) \Rightarrow x = \frac{1}{2} \times 640 \Rightarrow x = \mathbf{320\ cm}$.
Part (b): Touch of the jockey on the wire at a point at distance $x = 560$ cm from A, other than null point determined in part (a), will create a current in galvanometer and change pattern of current and uniform voltage drop along the wire. Accordingly, voltage equations are formed for the two loops as under –
Upper loop: $E - (I + i) \times \rho x - I\big((L - x)\rho + r\big) = 0 \Rightarrow I(\rho x + (L - x)\rho + r) = E - i\rho x$
$\Rightarrow I(L\rho + r) = E - i\rho x \Rightarrow I = \frac{E - i\rho x}{L\rho + r}$.
Lower Loop: $\frac{E}{2} - (I + i) \times \rho x - ir = 0 \Rightarrow I\rho x = \frac{E}{2} - i(r + \rho x) \Rightarrow I = \frac{E - 2i(r+\rho x)}{2\rho x}$
Combing the two equations $\frac{E - i\rho x}{L\rho + r} = \frac{E - 2i(r+\rho x)}{2\rho x} \Rightarrow (E - i\rho x) \times 2\rho x = \big(E - 2i(r + \rho x)\big)(L\rho + r)$. Substituting, the available values we get –
$$\left(E - i \times \frac{r}{40} \times 560\right) \times 2 \times \frac{r}{40} \times 560 = \left(E - 2i\left(r + \frac{r}{40} \times 560\right)\right)\left(600 \times \frac{r}{40} + r\right).$$
$$\Rightarrow (E - 14ir) \times 28r = \big(E - 2i(r + 14r)\big)16r \Rightarrow 7(E - 14ir) = 4\big(E - 2i(r + 14r)\big)$$
$$\Rightarrow 7E - 98ir = 4E - 120ir \Rightarrow 3E = -22ir \Rightarrow i = -\frac{3E}{22r}.$$
Thus, current in the galvanometer is $|i| = \left|-\frac{3E}{22r}\right| = \boldsymbol{\frac{3E}{22r}}$
Thus, answers are (a) 320 cm (b) $\boldsymbol{\frac{3E}{22r}}$
N.B.: 1. Here, loop equations have been framed differently by identifying branch currents instead of loop current.
2. Galvanometer is an instruments which indicated bidirectional current through it, unlike current measuring instrument, Hence, it is the magnitude of current through the galvanometer is relevant, and that what has been asked.</td></tr>
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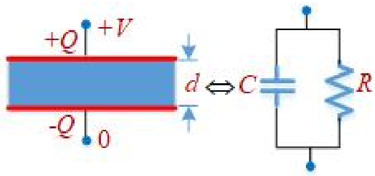
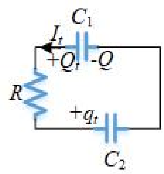
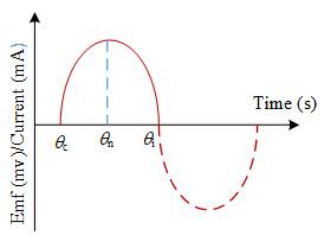
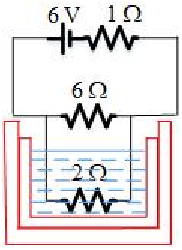
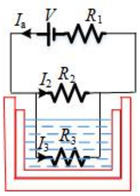
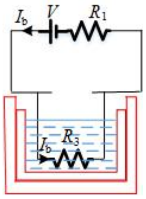
Q-3	A capacitor of capacitance C is connected to a battery of emf E at $t = 0$ through a resistance R. Find the maximum rate at which energy is stored in the capacitor. When does the rate has this maximum value?
A-3	$\frac{E^2}{4R}$, $CR\ln 2$
I-3	It is a case of capacitor charging in a RC circuit through a battery of emf E. Energy stored in a capacitor at any instant is $U_t = \frac{1}{2}Q_tV_t = \frac{1}{2}Q_t \times \frac{Q_t}{C} \Rightarrow U_t = \frac{{Q_t}^2}{2C}$. Therefore, rate at which energy is stored in the capacitor is $P_t = \frac{d}{dt}U_t = \frac{d}{dt}\frac{{Q_t}^2}{2C} = \frac{1}{2C} \times 2Q_t \times \frac{d}{dt}Q_t = \frac{Q_t}{C} \times \frac{d}{dt}Q_t$. Here, instantaneous charge on a capacitor is $Q_t = EC\left(1 - e^{-\frac{t}{RC}}\right)$ and $\frac{d}{dt}Q_t = EC \times \left(-\left(-\frac{1}{RC}\right)e^{-\frac{t}{RC}}\right) \Rightarrow \frac{d}{dt}Q_t = \frac{E}{R}e^{-\frac{t}{RC}}$. Thus, $P_t = \frac{EC\left(1-e^{-\frac{t}{RC}}\right)}{C} \times \frac{E}{R}e^{-\frac{t}{RC}}$. It solves into $P_t = \frac{E^2}{R}\left(e^{-\frac{t}{RC}} - e^{-\frac{2t}{RC}}\right)$. For maximum or minimum value of P_t the test is that value of t at which $\frac{d}{dt}P_t = 0$ and to judge it to be maximum is at that t determined in previous test $\frac{d^2}{dt^2}P_t < 0$ i.e. (-) and vice-versa for minimum. Accordingly, $\frac{d}{dt}P_t = \frac{d}{dt}\left[\frac{E^2}{R}\left(e^{-\frac{t}{RC}} - e^{-\frac{2t}{RC}}\right)\right] = \frac{E^2}{R}\left[-\frac{e^{-\frac{t}{RC}}}{RC} - \left(\frac{-2e^{-\frac{2t}{RC}}}{RC}\right)\right] = 0 \Rightarrow 2e^{-\frac{2t}{RC}} = e^{-\frac{t}{RC}}$. It leads to $e^{\frac{t}{RC}} = 2 \Rightarrow \frac{t}{RC} = \ln 2 \Rightarrow t =$ **$RC\ln 2$, is the answer of second part One.** Here solution second part is a pre-requisite for assertively arriving at answer to first part. Thus first derivative $\frac{d^2}{dt^2}P_t = \frac{d}{dt}\left(\frac{d}{dt}P_t\right) = \frac{d}{dt}\left(\frac{E^2}{R}\left[-\frac{e^{-\frac{t}{RC}}}{RC} + \frac{2e^{-\frac{2t}{RC}}}{RC}\right]\right) = \frac{E^2}{R^2C}\left[-\frac{4e^{-\frac{2t}{RC}}}{RC} - \left(-\frac{e^{-\frac{t}{RC}}}{RC}\right)\right] = \frac{E^2}{R^3C^2}\left[e^{-\frac{t}{RC}} - 4e^{-\frac{2t}{RC}}\right]$. Testing for maxima, with the value of $t = RC\ln 2$ of part 2 arrived at above value $e^{-\frac{t}{RC}} - 4e^{-\frac{2t}{RC}} < 0 \Rightarrow e^{\frac{t}{RC}} - 4 < 0$. To prove this inequality let $e^{\frac{t}{RC}} = x \Rightarrow e^{\frac{RC\ln 2}{RC}} = x \Rightarrow e^{\ln 2} = x \Rightarrow \ln 2 = \ln x \Rightarrow x = 2$. Accordingly, $e^{\frac{t}{RC}} - 4 < 0 \Rightarrow 2 - 4 = -2 < 0$. Thus it is established that $P_t = \frac{E^2}{R}\left(e^{-\frac{t}{RC}} - e^{-\frac{2t}{RC}}\right)$ is maximum at $t = RC\ln 2$. Therefore, $P_{Max} = \frac{E^2}{R}\left(e^{-\frac{RC\ln 2}{RC}} - e^{-\frac{2RC\ln 2}{RC}}\right) = \frac{E^2}{R}\left(e^{-\ln 2} - e^{-2\ln 2}\right) = \frac{E^2}{R}(p - q)$. Going forward involves little of logarithmic algebra and accordingly let $e^{-\ln 2} = p \Rightarrow -\ln 2 = \ln p \Rightarrow \ln\frac{1}{2} = \ln p \Rightarrow p = \frac{1}{2}$.Likewise, $e^{-2\ln 2} = q \Rightarrow q = e^{-\ln 2^2} \Rightarrow q = e^{-\ln 4} \Rightarrow \ln q = -\ln 4 \Rightarrow \ln q = \ln\frac{1}{4} \Rightarrow q = \frac{1}{4}$. Using values of p and q we have $P_{Max} = \frac{E^2}{R}\left(\frac{1}{2} - \frac{1}{4}\right) = \boldsymbol{\frac{E^2}{2R}}$ **is the answer.** **N.B.: 1.** In this problem solution of part 2 is required for arriving at solution of part 1, as discussed above. Such problems are sometimes encountered. **2**. This problem involves simple use of calculus and logarithmic algebra. **3**. It is only comfort of a student to using associated mathematics promptly will help him to make a quick leap and minimize solution steps.
Q-4	A capacitor of capacitance 12.0 μF is connected to a battery of emf 6.00 V and an internal resistance 1.00 Ω through resistanceless leads. 12.0 μs after the connections are made, what will be – (a) The current in the circuit, (b) The power delivered by the battery, (c) The power dissipated in heat, (d) The rate at which the energy stored in the capacitance is increasing.
A-4	(a) 2.21 A (b) 13.3 W (c) 4.88 W (d) 8.37 W
I-4	It is a problem of charging of a capacitor of capacitance $C = 12.0 \times 10^{-6}$ F, connected to a battery having $E = 6.00$ V and internal resistance $r = 1.00\ \Omega$, and external resistance $R = 0$. Basic equation of the circuit is of charging of a capacitor $Q_t = EC\left(1 - e^{-\frac{t}{RC}}\right)$ and $I_t = \frac{d}{dt}Q_t = EC \times \left(-\left(-\frac{1}{RC}\right)e^{-\frac{t}{RC}}\right) \Rightarrow I_t = \frac{E}{R}e^{-\frac{t}{RC}}$. It is taken forward in solving each part, at $t = 12.0 \times 10^{-12}$s, separately –

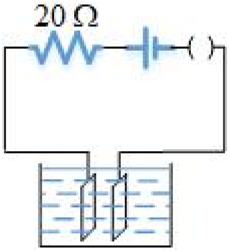
	Part (a): The value of current is $I_t = \frac{E}{R} e^{-\frac{t}{RC}} = \frac{6.00}{1.00} \times e^{-\frac{12.0\times10^{-6}}{1.00\times(12.0\times10^{-6})}} = 6.00 \times e^{-1} = \mathbf{2.21A}$ **is the answer.** **Part (b):** Power delivered by the battery $P_t = EI_t = 6.00 \times 2.21 = 13.26$ A say **13.3 A, is the answer**. **Part (c):** Power dissipated in heat is in internal resistance r and hence $P_{Ht} = I_t^2 r = (2.21)^2 \times 1.00 = \mathbf{4.88}$ **W is the answer.** **Part (d):** Energy stored in the battery is $U_t = \frac{1}{2}\frac{Q_t^2}{C}$, hence rate of energy stored $P_t = \frac{d}{dt}\left(\frac{1}{2}\frac{Q_t^2}{C}\right) = \frac{1}{2C}\frac{d}{dt}Q_t^2$. It leads to $P_t = \frac{2Q_t}{2C}\frac{d}{dt}Q_t = \frac{Q_t I_t}{C}$. Here, value of I_t is available from part (a), but Q_t has to be determined from charging equation. Using the available data $Q_t = 6.00 \times (12.0 \times 10^{-6}) \times \left(1 - e^{-\frac{12.0\times10^{-12}}{1.00\times(12.0\times10^{-6})}}\right) \Rightarrow Q_t = 72.0 \times 10^{-6} \times (1 - e^{-1}) = 72.0 \times 10^{-6} \times 0.632 = 45.5 \times 10^{-6}$. Using the available data $P_t = \frac{Q_t I_t}{C} = \frac{(45.5\times10^{-6})\times2.21}{12.0\times10^{-6}} = \mathbf{8.38}$ **W is the answer.** Thus, **answer is (a) 2.21 A (b) 13.3 W (c) 4.88 W (d) 8.37 W.**
Q-5	By evaluating $\int i^2 R dt$, show that when a capacitor is charged connecting it to a battery through a resistor, the energy dissipated as heat equals the energy stored in the capacitor.
A-5	-
I-5	This is a problem of charging of a capacitor of capacitance C, connected in series to a resistance R supplied by a battery of emf E. Equation of charge of a capacitor is $Q_t = EC\left(1 - e^{-\frac{t}{RC}}\right)$. Therefore, instantaneous current through the resistor is $I_t = \frac{d}{dt}Q_t = \frac{d}{dt}\left(EC\left(1 - e^{-\frac{t}{RC}}\right)\right) \Rightarrow I_t = EC\left(-\left(-\frac{1}{RC}\right)\right)e^{-\frac{t}{RC}} = \frac{E}{R}e^{-\frac{t}{RC}}$. Power consumed by the resistor at any instant is $P_t = I_t^2 R$. Therefore, heat dissipated by the resistor in time during charging is $H_t = \int_0^t I_t^2 R\, dt = R\int_0^t \left(\frac{E}{R}e^{-\frac{t}{RC}}\right)^2 dt = \frac{E^2}{R}\int_0^t e^{-\frac{2t}{RC}} dt = \left(\frac{E^2}{R}\right)\left(-\frac{RC}{2}\right)\left[e^{-\frac{2t}{RC}}\right]_0^t = \boldsymbol{\frac{E^2C}{2}\left(1 - e^{-\frac{2t}{RC}}\right)}$. Now, during charging instantaneous power supplied to the capacitor is $P_t = I_t V_t = I_t \frac{Q_t}{C}$. Using the available values $P_t = \left(\frac{E}{R}e^{-\frac{t}{RC}}\right)\left(\frac{EC\left(1-e^{-\frac{t}{RC}}\right)}{C}\right) = \frac{E^2}{R}\left(e^{-\frac{t}{RC}} - e^{-\frac{2t}{RC}}\right)$. Therefore, energy stored in the capacitor is $U = \int_0^t P_t dt$. It leads to $U_t = \int_0^t \left(\frac{E^2}{R}\left(e^{-\frac{t}{RC}} - e^{-\frac{2t}{RC}}\right)\right)dt = \frac{E^2}{R}\left[\int_0^t e^{-\frac{t}{RC}}dt - \int_0^t e^{-\frac{2t}{RC}}dt\right] = \frac{E^2}{R}\left[RC\left(1 - e^{-\frac{t}{RC}}\right) - \frac{RC}{2}\left(1 - e^{-\frac{2t}{RC}}\right)\right]$. It solves into $U_t = E^2C\left[\left(1 - e^{-\frac{t}{RC}}\right) - \frac{1}{2}\left(1 - e^{-\frac{2t}{RC}}\right)\right] = \frac{E^2C}{2}\left(1 - 2e^{-\frac{t}{RC}} + e^{-\frac{2t}{RC}}\right)$. Time taken for the capacitor to be fully charged is $t \to \infty$ and at that heat developed $H = U_\infty = \frac{E^2C}{2}\left(1 - e^{-\frac{2\infty}{RC}}\right) \Rightarrow \boldsymbol{H = \frac{E^2C}{2}}$ and energy stored in the capacitor is $U = U_\infty = \frac{E^2C}{2}\left(1 - 2e^{-\frac{\infty}{RC}} + e^{-\frac{2\infty}{RC}}\right) \Rightarrow \boldsymbol{U = \frac{E^2C}{2}}$. **It is thus proved that $\boldsymbol{H = U}$.** **N.B.: 1.** The problem states that capacitor is charged by connecting through a battery, without stating period of connection. It implies that capacitor is fully charged for which $t \to \infty$, and is used in final conclusion. **2.** From expression derived above the conclusion in this problem is not true for $0 < t < \infty$ and need not be taken as generic conclusion.
Q-6	A parallel-plate capacitor is filled with a dielectric material having resistivity ρ and dielectric constant K. The capacitor is charged and disconnected from the charging source. The capacitor is slowly discharged

	through the dielectric. Show that the time constant of the discharge is independent of all geometrical parameters like the plate area or separation between the plates. Find the time constant.
A-6	$\varepsilon_0 \rho K$
I-6	It is a case when dielectric filling the gap between plates of a parallel-plate capacitor is not pure dielectric, which is supposed to have infinite resistivity. Therefore, the capacitor when charged to a voltage say V and disconnected from the source would have a discharge circuit as shown in the figure. Here, capacitance of the parallel plate capacitor with dielectric having dielectric constant K is $C = \frac{\varepsilon_0 K A}{d}$, and resistance of the dielectric slab of resistivity is $R = \frac{\rho d}{A}$. Here, A is area of the plates and d is separation between the plates.  Time constant of a RC circuit is $\tau = RC = \left(\frac{\rho d}{A}\right) \times \left(\frac{\varepsilon_0 K A}{d}\right) = \rho \varepsilon_0 K \Rightarrow \tau = \boldsymbol{\varepsilon_0 \rho K}$ is the answer. **N.B.:** Since $\boldsymbol{\varepsilon_0}$ is a universal constant it is given precedence of material dependent constant ρ and K, while reporting the answer,
Q-7	A capacitor of capacitance C is given a charge Q. At $t = 0$, it is connected to an uncharged capacitor of equal capacitance through a resistance R. Find the charge on the second capacitor as a function of time.
A-7	$\frac{Q}{2}\left(1 - e^{-\frac{2t}{RC}}\right)$
I-7	Circuit of the given problem is shown in the figure. Charge on capacitor $C_1 = C$ is given a charge $Q_1 = Q$. This capacitor is connected to another identical capacitor C_2 through a resistance R in series.. It is a case of simultaneous charging-discharging of capacitors. While charging of a capacitor C_2 by a capacitor C_1 which is at a potential difference $V_t = \frac{Q_t}{C}$. Accordingly, the discharge equation of the circuit for $t > 0$ i$V_t - V_t - \frac{q_t}{C} - RI_t = 0 \Rightarrow V_t - \frac{q_t}{C} - R\frac{d}{dt}q_t = 0 \Rightarrow \frac{d}{dt}q_t = \frac{Q_t}{RC} - \frac{q_t}{RC}$. As per principle of conservation of charge discharge on isolated capacitors-circuit remains constant at $Q = Q_t + q_t \Rightarrow Q_t = Q - q_t$. Accordingly, the charging equation can be rewritten as $\frac{d}{dt}q_t = \frac{Q - q_t}{RC} - \frac{q_t}{RC} \Rightarrow \frac{d}{dt}q_t = \frac{Q - 2q_t}{RC} \Rightarrow \int \frac{dq_t}{Q - 2q_t} = \frac{1}{RC}\int dt$. This solves into $-\frac{1}{2}\ln(Q - 2q_t) = \frac{t}{Rc} + K \Rightarrow Q - 2q_t = K' e^{-\frac{2t}{RC}}$. At $t = 0$ the charge on te capacitor C_2 is $q_t = 0$, therefore, $Q - 0 = K'^{e^0} \Rightarrow K' = Q$. It leads to $Q - 2q_t = Qe^{-\frac{2t}{RC}} \Rightarrow 2q_t = Q\left(1 - e^{-\frac{2t}{RC}}\right)$. In its final form charge on capacitor C_2 is $q_t = \boldsymbol{\frac{Q}{2}\left(1 - e^{-\frac{2t}{RC}}\right)}$ **is the answer.**  **N.B.:** This problems prompts to visualize situations close to that occurring in practical circuits.
Q-8	Do all the thermocouples have a neutral temperature?
A-8	No
I-8	Emf of a thermocouple is $E = a\theta + \frac{1}{2}b\theta^2$ here, $\theta' = \theta_c + \theta$ where $\theta' > \theta_c$C is the temperature of hot junction while cold junction is maintained at 0^0C while a and b are constants specific to a pair of metals forming the thermocouple. This is an empirical equation approximating characteristic of a thermos couple as shown in the figure -  Thus for thermocouple-emf to be zero, $0 = a\theta + \frac{1}{2}b\theta^2 \Rightarrow \theta_i = \theta = -\frac{2a}{b}$. Whereas for maximum emf $\frac{d}{d\theta}E = a + \frac{1}{2} \times 2b\theta = 0 \Rightarrow \theta_n = \theta = -\frac{a}{b}$. If $\theta_c = 0^0$ C and temperatures are indicated in Celsius then $\theta_i = 2\theta_n$. It is to be noted that θ_n for a thermocouple is fixed and depends on variation of electron density with temperature forming the thermocouple.

	Occurrence of this point of inflexion called inversion or neutral temperature requires that values of a and b are signed oppositely. Therefore, neutral temperature would not occur when pair of metals having values of a and b are of opposite signs, this is not true e.g. Pb-Ag, Pb-Cu… Hence, **answer is No for all thermocouples.**
Q-8	The heat developed in a system is proportional to current through it – (a) It cannot be Thomson heat. (b) It cannot be Peltier heat (c) It cannot be Joule heat (d) It can be any of the three mentioned above
A-8	(c)
I-8	Let us analyze each of the given option – **Option (a):** In Thomson effect heat produced in conductor is proportional to the current passing through it. Hence, **this option is wrong.** **Option (b):** In Peltier effect heat produced in conductor is proportional to the current passing through it. Hence, t**his option is wrong.** **Option (c):** As per Joules' Law heat produced in conductor is proportional to the square of the current passing through it. Hence, t**his option is Correct.** **Option (d):** Since option (c) out of the three above is correct, hence **this option is wrong.** Thus, **answer is option (c).**
Q-9	Faraday constant – (a) depends on the amount of electrolyte (b) depends on the current in the electrolyte (c) is a universal constant (d) depends on the amount of charge passed through the electrolyte
A-9	(c)
I-9	Faraday's constant is defined as magnitude of charge per mole of electron. Avogadro's Number $N_A = 6.022 \times 10^{23}$ is number of molecules in One mol (M) of substance. Here, 1 gm-mol of substance is substance equal to molecular mass of substance. For example molar mass of hydrogen H_2 is 2 $(= 2 \times 1)$ while that of carbon is 12. Thus molar mass of methane CH4 is $16 = (12 + 2 \times 2)$. Thus molar mass of substance is based on atomic structure of atoms forming molecules of substance. Number of atoms per gram-mol of substance is $N = N_A \times M$ is a constant. Magnitude of charge of an electron is $e = 1.602 \times 10^{-19}$. Accordingly, charge of once gram of electrons is defined as Faraday's Constant is $F = N_A \times e = (6.022 \times 10^{23}) \times (1.602 \times 10^{-19}) = \mathbf{96.4 \times 10^3}$ **C/mol^{-1} is universal constant.** Here, *1 faraday of charge* 1*f* = 96.4×10^3C. **N.B.:** Electrochemical equivalent Z of substance is amount of substance deposited when 1 C charge (equivalent to 1A current for 1 s) passes through an electrolyte. Let a substance of molecular mass m and valency v is deposited through electrolysis will exchange charge $q = it$ which is equal to $q = v(N_A \times e) = vF$. Therefore, electrochemical equivalent of the substance, as per definition is, $\boldsymbol{Z} = \frac{m}{v(N_A \times e)} = \frac{\boldsymbol{m}}{\boldsymbol{vF}} = \frac{\boldsymbol{m}}{\boldsymbol{it}} \Rightarrow \boldsymbol{m = Zit}$.
Q-10	A copper strip AB and an iron strip AC are joined at A. The junction A is maintained at 0^0C and the free ends B and C are maintained at 100^0C. There is a potential difference between – (a) The two ends of the copper strip (b) The cooper end and the iron end at the junction (c) The two ends of the iron strip

	(d) The free ends B and C
A-10	All
I-10	Given system is an experimental set up of two different metal strips joined at one end and kept at 0^0C and other free ends of the two strips are maintained at 100^0C. Accordingly, - • There will be potential difference at the two free ends of copper strip, as per Thomson's Effect. Thus **option (a) is correct.** • There will be potential difference between ends of cooper and iron strips at the junction as per Seebeck effect. Thus **option (b) is correct.** • There will be potential difference at the two free ends of iron strip, as per Thomson's Effect. Thus **option (c) is correct.** • There will be potential difference between free ends of cooper and iron strips as per Seebeck effect. Thus **option (d) is correct.** Thus, **answer is all options are correct.**
Q-11	The constant a and b for the pair of silver-lead are 2.50 μV^0C^{-1} and 0.012 μV^0C^{-2} respectively. For a silver-lead thermocouple with colder junction at 0^0C – (a) There will be no neutral temperature (b) There will be no inversion temperature (c) There will not be any thermos-emf even if the junctions are kept at different temperature (d) There will be no current in the thermocouple even if the junctions are kept at different temperature.
A-11	(a), (b)
I-11	Equation of thermocouple emf is $E = a\theta + \frac{1}{2}b\theta^2$. Thus requirement of neutral temperature is when slope $\frac{dE}{d\theta} = 0$. It necessitates $a + b\theta = 0 \Rightarrow \theta = -\frac{a}{b}$. Since temperature of cold junction is $\theta_c = 0$, hence neutral temperature $\theta_n > \theta_c \Rightarrow \theta_n > 0$ implies that θ is positive. In the instant case with positive values of a and b θ is negative. Hence neutral temperature would not exit. Thus, **option (a) is correct.** For inversion temperature to exist, it has to be preceded by neutral temperature. Since there is no neutral temperature as concluded above, there will be no inversion temperature. Thus, **option (b) is correct.** Since both $a \neq 0$ and $b \neq 0$ in case of the two junctions kept at different temperatures therefore will be thermo-emf. Thus, **option (c) is incorrect.** In view of the existence of thermo-emf as per conclusion in option (c) there will be current in the thermocouple, **making option (d) incorrect.** Thus, **answers are option (a) and (b).**
Q-12	The electrochemical equivalent of a material depends on – (a) The nature of the material (b) The current through the electrolyte containing the material (c) The amount of charge passed through the electrolyte (d) The amount of this material present in the electrolyte
A-12	(a)
I-12	Electrochemical equivalent Z of substance is amount of substance deposited when 1 C charge (equivalent to 1A current for 1 s) passes through an electrolyte. Let mass of substance M and valency v is deposited through electrolysis will exchange charge $q = it$ which is equal to $q = v(N_A \times e) = vF$. Therefore, electrochemical equivalent of the substance, as per definition is, $Z = \frac{M}{v(N_A \times e)} = \frac{M}{vF} = \frac{M}{it}$. Mass of substance $M = nm$, here is m molar of substance say 16 for carbon and is specific to each material. And n is number on moles . If $it =$ 1C then $Z = m$. Thus, **option (a) is correct.**

	Discussions on option (a) above, electrochemical equivalent being characteristic to material does not depend upon current through electrolyte, option (b), amount of charge $Q = it$ in option (c), and amount of material present in electrolyte option (d). Thus, **answer is option (a).**
Q-13	An immersion heater rated 1000 W, 220 V is used to heat 0.01 m^3 of water. Assuming that the power is supplied at 220 V and 60% of the power supplied is used to heat the water, how long will it take to increase the temperature of the water from 15^{0}C to 40^{0}C ?
A-13	29 minutes
I-13	Amount of heat required to raise temperature of water $V = 0.01$ m^3 whose mass (density of water being $\rho = 1000$ kg /m^3) is $M = \rho V = 1000 \times 0.01 = 10$ kg. Its temperature is to be raised by $\Delta T = 40 - 15 = 25$ ^{0}C. Therefore heat required is $H = M \times s \times \Delta T$, here specific heat of water is $s = 4200$ J/kg/ ^{0}C. Accordingly, $H = 10 \times 4200 \times 25 = 1050 \times 10^3$J. It is given that 60% of input energy is utilized to heat water, therefore amount of electrical energy consumed is $E = (1050 \times 10^3) \times \frac{100}{60} =\approx 1750 \times 10^3$J. With the given specification of heater $P = 1000$ W, 220 V, required electrical energy is $E = P \times t \Rightarrow t = \frac{E}{P}$, here t is time in s. Therefore, time in minutes will be $t' = \frac{E}{P\times 60} = \frac{1750\times 10^3}{1000\times 60} = 29$ minutes is the answer. **N.B.:** Here it is given that immersion heater is used at its rated voltage and hence voltage of the heater is notional and is not required to be used in calculations
Q-14	The 2.0 Ω resistor shown in the figure is dipped into a calorimeter containing water. The heat capacity of the calorimeter together with water is 2000 JK^{-1}. (a) If the circuit is active for 15 minutes, what would be the rise in the temperature of the water? (b) Suppose the 6.0 W resistor gets burnt, what would be the rise in the temperature of water in the next 15 minutes? 
A-14	(a) 2.9^{0}C (b) 3.6^{0}C
I-14	Heating of water in the given problem is dependent on heat $H = I^2Rt$ developed in $R_3 = 2$ Ω, here $t = 15 \times 60 = 900$ s is the time for which the circuit is active. Accordingly, rise of temperature of water is $H = S \times \Delta T$, here $S = 2000$ JK^{-1} is the heat capacity of heat system consisting of calorimeter and water. Here, units of electrical energy and heat capacity in joules and therefore, use of mechanical equivalent of heat J is not required. The problem has two parts having change in the electrical circuit where battery voltage is $V = 6$ V, resistances $R_1 = 1$ Ω, $R_2 = 6$ Ω, and $R_1 = 2$ Ω. Whereas, the thermal system remains unchanged. Each part is solved separately.  **Part (a):** Considering series parallel combination of the circuit, equivalent resistance of the circuit is $R_{Eq} = R_1 + \frac{R_2R_3}{R_2+R_3} = 1 + \frac{2\times 6}{2+6} = 2.5$ Ω. Therefore, current in the circuit $I_a = \frac{V}{R_{Eq}} = \frac{6}{2.5} = 2.4$ A. This current would distribute $I_a = I_2 + I_3$ among R_2 and R_3 in inverse proportion of their resistances such that $\frac{I_3}{I_2} = \frac{R_2}{R_3} \Rightarrow \frac{I_3}{I_2+I_3} = \frac{R_2}{R_2+R_3} \Rightarrow I_3 = \left(\frac{R_2}{R_2+R_3}\right) \times I_a$. Using the available data $I_3 = \left(\frac{6}{6+2}\right) \times 2.4 = 1.8$ A. Accordingly, $\Delta T_a = \frac{{I_3}^2R_3t}{S} = \frac{1.8^2\times 2\times 900}{2000} =$ **2.9 ^{0}C is answer of the apart (a).**  **Part (b):** In this part it is given that R_2 gets burnt. Thus the electrical circuit becomes a series combination of R_1 and R_3. Thus current in the circuit $I_b = \frac{V}{R_1+R_3} = \frac{6}{1+2} = 2$ Amp. Therefore, $\Delta T_b = \frac{{I_b}^2R_3t}{S} = \frac{2^2\times 2\times 900}{2000} =$ **3.6 ^{0}C is answer of the apart (b).** Hence, **answers are (a) 2.9^{0}C (b) 3.6^{0}C**

	N.B.: Incremental rise of temperature in each part is to be determined and not the cumulative rise in temperature. It needs to be noted carefully to be right at the answer.
Q-15	The temperature of the junction of a bismuth-silver thermocouple are maintained at 0^0C and 0.001^0C. Find the thermo-emf (Seebeck emf) developed. For bismuth-silver, $a = -46 \times 10^{-6}$ V^{0}C^{-1} and $b = -0.48 \times 10^{-6}$ V^{0}C^{-2}.
A-16	-4.6×10^{-8} V
I-16	The emf equation of the thermocouple is $E = a\theta + \frac{1}{2}b\theta^2$. Using the given data where temperature of the junction $\theta = \theta_C + 0.001^0$C is given while the other junction is maintained at $\theta_C = 0\ ^0$C. Accordingly, the thermo-emf that is developed in the thermo-couple is $E = (-46 \times 10^{-6}) \times 0.001 + \frac{1}{2}(-0.48 \times 10^{-6} \times (0.001)^2) \Rightarrow E = \mathbf{-0.46 \times 10^{-8}}$ **V is the answer.**
Q-17	Find the thermo-emf developed in a copper-silver thermocouple, when the junctions are kept at 0^0C and 40^0C. For silver $a_{Ag-Pb} = 2.5 \times 10^{-6}$ V^{0}C^{-1} and $b_{Ag-Pb} = 0.012 \times 10^{-6}$ V^{0}C^{-2} and for copper $a_{Cu-Pb} = 2.76 \times 10^{-6}$ V^{0}C^{-1} and $b_{Cu-Pb} = 0.012 \times 10^{-6}$ V^{0}C^{-2}.
A-17	1.04×10^{-5} V
I-17	With the given values of a and b for metals forming thermo-couple $a_{Cu-Ag} = a_{Cu-Pb} - a_{Ag-Pb}$, it leads to $a_{Cu-Ag} = 2.76 \times 10^{-6} - 2.5 \times 10^{-6} = 0.26 \times 10^{-6}$ V^{0}C^{-1} and $b_{Cu-Ag} = b_{Cu-Pb} - b_{Ag-Pb} = 0$, since both values on R.H.S are equal. Further given that temperature of cold junction is $\theta_C = 0^0$C and that of the hot junction is $\theta_H = 40\ ^0$C, accordingly $\theta = \theta_H - \theta_C = 40^0$C. Therefore, as per equation $E = a\theta + b\theta^2 \Rightarrow E = a_{Cu-Ag} \times 40 + 0 = (0.26 \times 10^{-6}) \times 40 = \mathbf{1.04 \times 10^{-5}}$ **V is the answer.**
Q-18	Find the neutral temperature and inversion temperature of copper-iron thermocouple if the reference junction is kept at 0^0C. For iron $a = 16.6 \times 10^{-6}$ V^{0}C^{-1} and $b = -0.030 \times 10^{-6}$ V^{0}C^{-2} and for copper $a = 2.76 \times 10^{-6}$ V^{0}C^{-1} and $b = 0.012 \times 10^{-6}$ V^{0}C^{-2}.
A-18	330^0C, 659^0C
I-18	Equation of thermo-emf is $E = a\theta + \frac{1}{2}b\theta^2$. In this neutral temperature is at $\frac{d}{d\theta}E = \frac{d}{d\theta}(a\theta + b\theta^2) = a + 2b\theta = 0$ or with the given $\theta_C = 0$, at $\theta = -\frac{a}{b} = \theta_n$. For the given copper-iron thermocouple $a_{Cu-Fe} = a_{Cu} - a_{Fe} \Rightarrow a_{Cu-Fe} = 2.76 \times 10^{-6} - 16.6 \times 10^{-6} = -13.84 \times 10^{-6}$ V^{0}C^{-1}and $b_{Cu-Fe} = b_{Cu} - b_{Fe} \Rightarrow b_{Cu-Fe} = 0.12 \times 10^{-6} - (-0.030) \times 10^{-6} = 0.042 \times 10^{-6}$ V^{0}C^{-1}. Therefore, $\theta_n = -\frac{(-13.84\times10^{-6})}{(0.042\times10^{-6})} = \mathbf{330\ ^0C}$ **is one part of the answer.** For inversion temperature θ_i we have $E = a\theta_i + \frac{1}{2}b\theta_i{}^2 = 0 \Rightarrow \theta_i = -2 \times \frac{a}{b} = -2 \times \left(\frac{-13.84\times10^{-6}}{0.042\times10^{-6}}\right)$. It leads to $\theta_i = \mathbf{659\ ^0C}$ **is one part of the answer.** Thus, **answers are 330^{0}C, 659^{0}C**
Q-19	Figure shows an electrolyte of AgCl through which a current is passed. It is observed that 2.68 g of silver is deposited in 10 minutes on the cathode. Find the heat developed in the 20 Ω resistor during this period. Atomic mass of silver is 107.9 g.mol^{-1}. 
A-19	190 kJ

I-10	Mass of silver (M) deposited during electrolysis is $M = \frac{m}{v(A_v e)} \times I \times t \Rightarrow I = \frac{96500 \times M}{m \times t}$ …(1), here given that mass of silver deposited $M = 2.68$ g, atomic mass of sliver $m = 107.9$ g.mol^{-1}, valency of silver $v = 1$, Avogadro's number A_v and charge of an electron e such that $A_v e = 96500$ a constant, $t = 10 \times 60 = 600$ s for which a current I is passed through the electrolyte. Therefore, as desired, heat developed in resistor $R = 20\ \Omega$ is to be determined, which as per Joules' Law is $H = I^2 Rt$ J….(2). Combining (1) and (2) $H = \left(\frac{96500 \times M}{m \times t}\right)^2 Rt = \left(\frac{96500 \times M}{m}\right)^2 \times \frac{R}{t}$…(3). Using the available data $H = \left(\frac{96500 \times 2.68}{107.9}\right)^2 \times \frac{20}{600} = 191496$ J. Using principle of significant digits $H =$ **190 kJ is the answer.**
Q-20	A plate of area 10 cm^2 is to be electroplated with copper (density 9000 kg.m^{-3}) to a thickness 10 micrometer on both sides, using a cell of 12 V. Calculate the energy spent by the cell in the process of deposition. If this energy is used to heat 100 g of water, calculate the rise in temperature of the water. ECE of copper is 3×10^{-7} kg.C^{-1} and specific heat capacity of water is 4200 J.kg^{-1}.K^{-1}.
A-20	7.2 kJ, 17 K
I-20	This problem has four parts – **Part (a):** electrolytic deposition copper of thickness $d = 10 \times 10^{-6}$m on both sides of plate having area $A = 10 \times 10^{-4}$m^2, density of copper is $\rho = 9000$ kg.m^{-3}. This will lead to geometrical determination of mass M of copper deposited on the given plate. Accordingly, using the available data, $\boldsymbol{M} = V\rho = (2A \times d)\rho = (2 \times (10 \times 10^{-4}) \times 10 \times 10^{-6}) \times (9000) = \mathbf{1.8} \times \mathbf{10^{-4}}$ **kg.** **Part (b):** Amount of charge $Q = It$ passed during electrolysis for deposition of mass M of copper is $M = ZQ$ given that electrochemical equivalent of copper is $Z = 3 \times 10^{-7}$ kg.C^{-1}. Accordingly, $\boldsymbol{Q} = \frac{M}{Z} = \frac{M}{Z} = \frac{1.8 \times 10^{-4}}{3 \times 10^{-7}} = \mathbf{6.0 \times 10^2 C}$ **Part (c):** Amount of energy spent by cell $U = VIt = VQ$, here cell has $V = 12$ V.Therefore, $\boldsymbol{U} = 12 \times (6.0 \times 10^2) = 7.2 \times 10^3$ J or **7.2 kJ** **Part (d):** If energy calculated in part (c) is spent on heating water of mass $m_w = 0.1$ kg the rise of temperature of the water whose specific heat is $s = 4200$ J.kg^{-1}.K^{-1}is $U = H = m_w s \Delta T \Rightarrow \Delta T = \frac{U}{m_w s} = \frac{7.2 \times 10^3}{0.1 \times 4200} = 17$ K **Thus, answers are 7.2 kJ, 17 K.** N.B.: Decomposition of problems in step-wise solution makes it easier. This is called algorithmic approach of solving any problem howsoever complex it may appear, at a first glance. Such an approach is extremely useful in solving an unknown problem, as one moves forward.

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