

PH 220: Physics for Scientists & Engineers II

Exam 2 Comprehensive Problem Set & Practice Worksheet

Unit 2 • Electric Potential (Ch 7) • Capacitance & Dielectrics (Ch 8) • Current & Resistance (Ch 9) • DC Circuits (Ch 10)

Student Name: _____ Date: _____ Score: _____ / 44

UNIT 2 OFFICIAL FORMULA REFERENCE SHEET

EXAM 2 PERMITTED EQUATIONS

Electric Potential & Work (Ch 7)

$$\Delta V = V_B - V_A = - \int_A^B \vec{E} \cdot d\vec{l}$$
$$V_{pt} = \frac{kq}{r}, \quad U_{pt} = \frac{kq_1q_2}{r}$$
$$\Delta U = q\Delta V, \quad W_{\text{field}} = -\Delta U$$
$$\vec{E} = -\vec{\nabla}V = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right)$$
$$V(x) = k \int \frac{dq}{r}$$

Capacitance & Dielectrics (Ch 8)

$$C = \frac{Q}{V}, \quad C_0 = \frac{\epsilon_0 A}{d}, \quad C = \kappa C_0$$
$$C_{\text{parallel}} = \sum C_i, \quad \frac{1}{C_{\text{series}}} = \sum \frac{1}{C_i}$$
$$U_C = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$$
$$u_E = \frac{1}{2}\epsilon_0 E^2, \quad E = \frac{E_0}{\kappa}$$
$$\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2)$$

Current, Resistance & DC Circuits (Ch 9–10)

$$I = \frac{dQ}{dt} = nqv_dA, \quad \vec{J} = \sigma \vec{E} = \frac{\vec{E}}{\rho}$$
$$R = \frac{\rho L}{A}, \quad V = IR, \quad P = IV = I^2R = \frac{V^2}{R}$$
$$\sum I_{\text{in}} = \sum I_{\text{out}}, \quad \sum \Delta V = 0$$
$$R_{\text{series}} = \sum R_i, \quad \frac{1}{R_{\text{parallel}}} = \sum \frac{1}{R_i}$$

RC Charge: $q(t) = C\mathcal{E}(1 - e^{-t/\tau}), \quad \tau = RC$
RC Discharge: $q(t) = Q_0e^{-t/\tau}, \quad I(t) = -\frac{Q_0}{\tau}e^{-t/\tau}$

Part I: Practice Exam 2 Problems (Core Coverage • Problems 1–16) 16 Problems

PRACTICE EXAM Practice Exam #1 — Zero Potential Position Between Point Charges Ch 7: Electric Potential

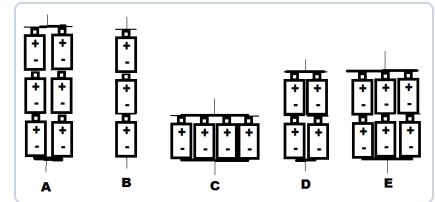
If a +27.8 μC charge is placed 35.0 cm from a −18.8 μC charge, where would an electric potential of zero exist?

- ☐ (A) Only at infinity
- ☐ (B) Impossible to determine
- ☐ (C) In line with the charges, in between them
- ☐ (D) In line with the charges, by the -18.8 μC charge but on the opposite side as the +27.8 μC
- ☐ (E) In line with the charges, by the +27.8 μC charge but on the opposite side as the -18.8 μC

WORKSPACE / REASONING

Selected Answer: []

Which configuration would have a flashlight last the longest, assuming all batteries are created equal and connected as shown?

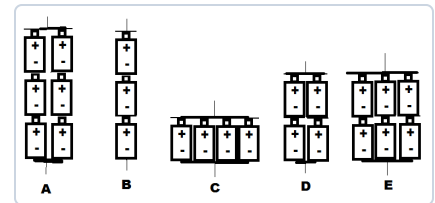


- ☐ (A) Configuration A
- ☐ (B) Configuration B
- ☐ (C) Configuration C (all batteries in parallel)
- ☐ (D) Configuration D
- ☐ (E) Configuration E

WORKSPACE / REASONING

Selected Answer: []

Which one of the battery combinations shown has the least voltage loss due to internal resistance, assuming they are connected to identical bulbs R and have same values of r per battery?



- ☐ (A) Configuration A
- ☐ (B) Configuration B
- ☐ (C) Configuration C (all batteries in parallel)
- ☐ (D) Configuration D
- ☐ (E) Configuration E

WORKSPACE / REASONING

Selected Answer: []

A single capacitor is charged to a potential of V_0 then removed from a circuit. If a dielectric is then placed between the plates with $\kappa = 3$, which of the following terms are correct for this 'new' capacitor? (Select all that apply)

- ☐ (A) $C = \frac{1}{3} C_0$
- ☐ (B) $C = 3C_0$
- ☐ (C) $V = \frac{1}{3} V_0$
- ☐ (D) $V = 3V_0$
- ☐ (E) $Q = \frac{1}{3} Q_0$
- ☐ (F) $Q = 3Q_0$
- ☐ (G) $E = \frac{1}{3} E_0$
- ☐ (H) $E = 3E_0$

WORKSPACE / REASONING

Selected Answer:

If the terminal voltage of a battery is 12 V and resistors $R_1 = 8\ \Omega$ and $R_2 = 6\ \Omega$ are connected in parallel in this circuit, what is the ratio of the currents through these two resistors I_1/I_2 ?

- ☐ (A) $4/3$
- ☐ (B) $3/4$
- ☐ (C) $3/2$
- ☐ (D) $2/3$
- ☐ (E) $1/2$
- ☐ (F) $2/1$

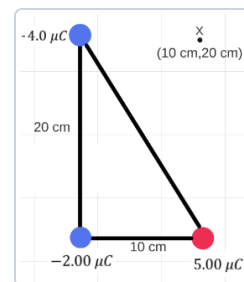
WORKSPACE / REASONING

Selected Answer:

How much energy would be required to build the following charge configuration, bringing the charges in from infinity?

Charges are arranged in a right triangle:

- $q_a = -4.00 \mu\text{C}$ at $(0, 20.0 \text{ cm})$
- $q_b = -2.00 \mu\text{C}$ at $(0, 0)$
- $q_c = 5.00 \mu\text{C}$ at $(10.0 \text{ cm}, 0)$



SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWER)

If the electric field along the x-axis follows the equation $\vec{E}(x) = \left(300x^3 - \frac{2}{x}\right) \hat{i} \text{ N/C}$, and the potential is known to be $V_0 = -20.0 \text{ V}$ at $x = 10.0 \text{ cm}$, what is the electric potential at $x = 1.50 \text{ m}$?

SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWER)

A potential of 9.00 V is placed across a capacitor and eventually reaches a charge of $Q = 24.5 \text{ nC}$. If the plates are separated by 1.50 mm , what is their plate area?

SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWER)

A capacitor with circular parallel plates of radius 25.5 cm and separation distance of 0.575 cm has been charged up until there is an electric field of $5.76 \times 10^6 \text{ V/m}$ between them. If this capacitor is separated from the circuit and a dielectric with $\kappa = 2.50$ is placed between them, what is the electric potential between the plates?

SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWER)

A wire is made out of gold and has a length of 11.1 m and a diameter of 0.222 mm (resistivity $\rho = 2.44 \times 10^{-8} \Omega \cdot \text{m}$). If the same amount of gold is used to make a new wire, but with half the resistance of the first, how long would it be?

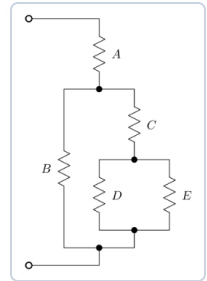
SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWER)

If it takes $24.5 \mu\text{s}$ to discharge a capacitor connected in series with a 55.5Ω resistor to 3.00% of its initial charge, what is the capacitance of this capacitor?

SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWER)

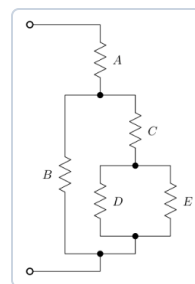
Each resistor shown in the diagram has a resistance of $6.00\ \Omega$, and an electromotive potential of $12.0\ \text{V}$ is placed across the terminals.

Find the electric current flowing through each individual resistor: I_A , I_B , I_C , I_D , and I_E .

**CIRCUIT REDUCTION & CALCULATION WORKSPACE**

Using the currents found in the previous circuit ($R = 6.00\ \Omega$ each, $I_A = 1.25\ \text{A}$, $I_B = 0.75\ \text{A}$, $I_C = 0.50\ \text{A}$, $I_D = 0.25\ \text{A}$, $I_E = 0.25\ \text{A}$):

Calculate the electrical power dissipated by each individual resistor (P_A , P_B , P_C , P_D , P_E) and the total power P_{total} delivered to the network.

**CIRCUIT REDUCTION & CALCULATION WORKSPACE**

An electron and a positron ($m_e = 9.11 \times 10^{-31} \text{ kg}$, $q = \pm 1.60 \times 10^{-19} \text{ C}$), initially separated by 100 nm, are launched directly away from each other along a line at $v_0 = 4.75 \times 10^4 \text{ m/s}$ each.

- (a) Find their maximum separation distance.
- (b) What is the maximum separation if a proton and antiproton ($m_p = 1.67 \times 10^{-27} \text{ kg}$) are used with initial separation 0.0500 nm and the same initial launch speeds?
- (c) Calculate the escape velocity for both particle pairs.
- (d) If an electron and proton are fired away from each other from initial separation 1.00 nm so that momentum and energy conservation bring them to rest simultaneously at separation 1.00 mm, find the initial speeds v_e and v_p .

SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWERS)

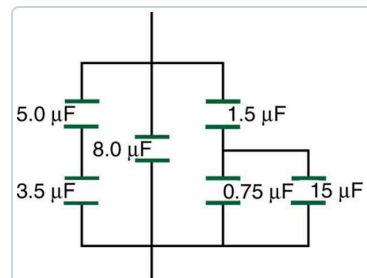
A capacitor is made from two flat parallel plates spaced 0.40 mm apart. When a charge of $0.020 \text{ } \mu\text{C}$ is placed on the plates, the potential difference between them is 250 V .

- (a) Find the capacitance C .
- (b) Find the area of each plate A .
- (c) Find the charge Q on the plates when the potential difference is increased to 500 V .
- (d) What maximum potential difference can be applied before the electric field exceeds 3.0 MV/m ?
- (e) How much energy is stored in the capacitor at that maximum potential?

SHOW FULL DERIVATION & CALCULATIONS (BOX YOUR FINAL ANSWERS)

For the capacitor circuit shown in the diagram:

- (a) Find the effective capacitance of the circuit.
- (b) If connected to a 9.00 V battery, find the potential difference across each of the six capacitors (V_5 , $V_{3.5}$, V_8 , $V_{1.5}$, $V_{0.75}$, V_{15}).
- (c) Find the stored electrostatic energy in each capacitor and the total stored energy.

**NETWORK REDUCTION, POTENTIAL TRAVERSAL & ENERGY WORKSPACE**

GROUP WORK Group Work 7.1 — Speed of Charged Particle from Electron-Volt Kinetic Energy

Ch 7: Electric Potential

What is the speed of a proton ($m_p = 1.67 \times 10^{-27}$ kg, $q = 1.60 \times 10^{-19}$ C) with 3,000 eV of kinetic energy?

SHOW WORK • CALCULATIONS • FORMULAS

Final Answer: _____ [m/s]

GROUP WORK Group Work 7.2 — Maximum Speed in Quadratic Potential with Turning Points

Ch 7: Electric Potential

An electric potential along the x-axis is given by $V(x) = 4000x^2$ (with V in volts and x in meters). A particle of mass $m = 1.0$ g and charge $q = 15$ nC moves in this potential and has turning points at $x = \pm 9.0$ cm. What is the maximum speed of the particle?

SHOW WORK • CALCULATIONS • FORMULAS

Final Answer: _____ [m/s]

GROUP WORK Group Work 7.3 — Distance of Closest Approach to Lead Nucleus

Ch 7: Electric Potential

A proton is shot toward the nucleus of a lead atom ($Z = 82$, diameter of nucleus = 14.0 fm, radius $R_{\text{Pb}} = 7.0$ fm). The proton is fired at an initial speed of $v_0 = 5.0 \times 10^7$ m/s from far away. What is its distance of closest approach to the *surface* of the lead nucleus? (Assume the lead nucleus remains stationary).

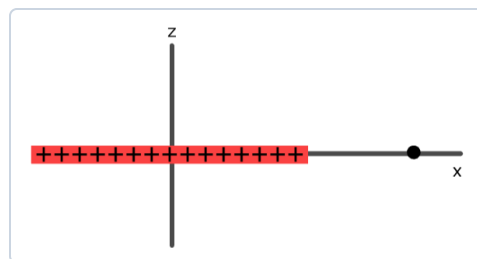
SHOW WORK • CALCULATIONS • FORMULAS

Final Answer: _____ [fm]

Two uniformly charged conducting spheres are placed with their centers 125 cm apart:

- Left sphere A : $q_1 = 150 \text{ nC}$, radius $r_1 = 45.0 \text{ cm}$
- Right sphere B : $q_2 = 50.0 \text{ nC}$, radius $r_2 = 15.0 \text{ cm}$

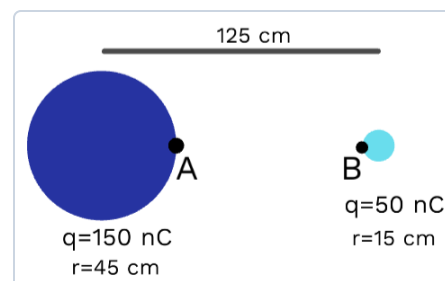
What is the magnitude of the potential difference between point a (on surface of A) and point b (on surface of B)?



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Final Answer: _____ [V]

A thin rod of length L carries a total uniform positive charge Q . It lies along the x-axis centered at the origin (from $x = -L/2$ to $x = +L/2$). Which of the following is the correct mathematical expression for the electric potential at a point on the x-axis at distance $x > L/2$?



- [] (A) $V = (kQ/L) \ln[(x + L/2) / (x - L/2)]$
- [] (B) $V = (kQ/L) \ln[(x - L/2) / (x + L/2)]$
- [] (C) $V = kQ / (x^2 - L^2/4)$
- [] (D) $V = (2kQ/L) [x / \sqrt{(x^2 + L^2/4)}]$

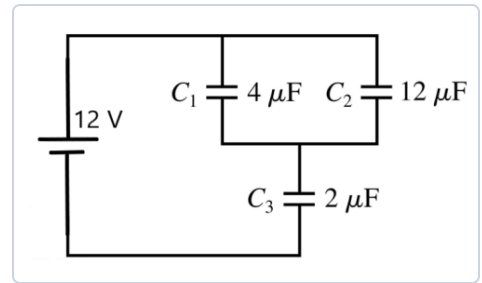
WORKSPACE / REASONING

Selected Answer: []

Three square metal plates ($10\text{ cm} \times 10\text{ cm}$, area $A = 0.010\text{ m}^2$) are positioned along the x-axis: plate 1 at $x = 0$ carries -50 nC , plate 2 at $x = 10\text{ cm}$ carries $+100\text{ nC}$, plate 3 at $x = 20\text{ cm}$ carries -50 nC . Let $V(0) = 0\text{ V}$.

Find the electric potential V at:

- $x = 5.0\text{ cm}$
- $x = 10.0\text{ cm}$ (at center plate)
- What is the magnitude of the electric field E between the first two plates ($0 < x < 10\text{ cm}$)?

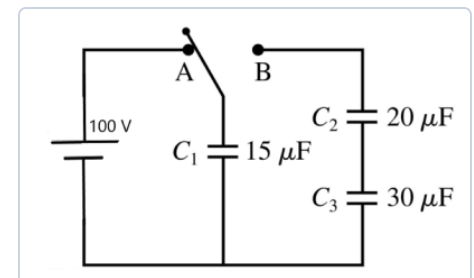


SHOW WORK FOR ALL SUB-PARTS

- (a) Potential at $x = 5\text{ cm}$ (kV): _____ [kV] (b) Potential at $x = 10\text{ cm}$ (kV): _____ [kV]
 (c) Field magnitude E (kV/m): _____ [kV/m]

Initially, the switch is in position A , charging capacitor $C_1 = 15.0\text{ μF}$ to 100 V while $C_2 = 20.0\text{ μF}$ and $C_3 = 30.0\text{ μF}$ are completely uncharged. The switch is then flipped to position B , connecting C_1 in parallel across the series combination of C_2 and C_3 .

Find the final charge and potential difference on each capacitor:



SHOW WORK FOR ALL SUB-PARTS

- Charge Q_1 (μC): _____ [μC] Voltage V_1 (V): _____ [V]
 Charge Q_2 & Q_3 (μC): _____ [μC] Voltage V_2 (V): _____ [V]
 Voltage V_3 (V): _____ [V]

The electron beam inside an old cathode ray television tube has a diameter of 0.40 mm and carries a beam current of $50.0 \mu\text{A}$. The electrons strike the screen at speed $v = 4.0 \times 10^7 \text{ m/s}$ and transfer all kinetic energy upon impact.

- (a) How many electrons strike the screen each second?
- (b) What is the current density J in the beam?
- (c) What electrical impact power is delivered to the screen?

SHOW WORK FOR ALL SUB-PARTS

(a) Electrons per second: _____ [e^-/s] (b) Current Density J (A/m^2): _____ [A/m^2]
(c) Delivered Power (W): _____ [W]

The current supplied to an air conditioner is 4.00 A through a 10-gauge wire with diameter $d = 2.60 \text{ mm}$. The free electron density of copper is $n_e = 8.48 \times 10^{28} \text{ m}^{-3}$.

- (a) Find the current density J .
- (b) Find the electron drift velocity v_d .

SHOW WORK FOR ALL SUB-PARTS

(a) Current Density J (A/m^2): _____ [A/m^2] (b) Drift Velocity v_d (m/s): _____ [m/s]

A 5.00 mm diameter proton beam carries a total current of 1.50 mA. The current density in the beam increases linearly with radial distance from center: $J(r) = J_{\text{edge}} \left(\frac{r}{R} \right)$, where $R = 2.50$ mm is the beam radius. Determine the edge current density J_{edge} .

SHOW WORK • CALCULATIONS • FORMULAS

Final Answer: _____ [A/m²]

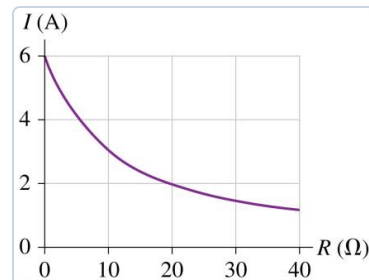
The total charge that has entered a wire at time t is given by $Q(t) = (20.0 \text{ C})(1 - e^{-t/2.0 \text{ s}})$. At what time t has the current decayed to exactly $\frac{1}{3}$ of its maximum initial value?

SHOW WORK • CALCULATIONS • FORMULAS

Final Answer: _____ [s]

A variable load resistor R is connected across the terminals of a real battery. The graph shows the circuit current I as a function of external load resistance R . At $R = 0\ \Omega$, $I = 6.0\ \text{A}$; at $R = 10.0\ \Omega$, $I = 3.0\ \text{A}$; at $R = 20.0\ \Omega$, $I = 2.0\ \text{A}$.

Determine the battery EMF $\mathcal{E}$ and internal resistance r :



SHOW WORK FOR ALL SUB-PARTS

Battery EMF (V): _____ [V] Internal Resistance r (Ω): _____ [Ω]

You have three resistors ($2.0\ \Omega$, $3.0\ \Omega$, $6.0\ \Omega$) and an ideal $6.0\ \text{V}$ battery. Which arrangement of all three resistors causes the battery to deliver exactly $9.0\ \text{W}$ of power?

- ☐ (A) The $2.0\ \Omega$ resistor in series with the parallel combination of $3.0\ \Omega$ and $6.0\ \Omega$
- ☐ (B) All three resistors connected in parallel
- ☐ (C) All three resistors connected in series
- ☐ (D) The $6.0\ \Omega$ resistor in series with the parallel combination of $2.0\ \Omega$ and $3.0\ \Omega$

WORKSPACE / REASONING

Selected Answer: []

An initially uncharged $1.50 \mu\text{F}$ capacitor is connected in series with a 500Ω resistor and a 6.16 V battery.

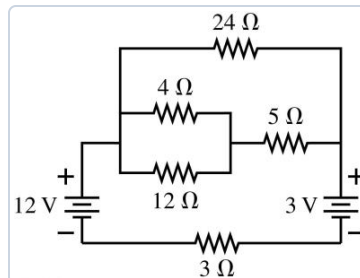
- Find the initial current I_0 .
- Find the circuit time constant τ .
- Find the current after one time constant ($t = \tau$).
- Find the capacitor voltage after one time constant.

SHOW WORK FOR ALL SUB-PARTS

(a) Initial Current I_0 (mA): _____ [mA] (b) Time Constant τ (ms): _____ [ms]
 (c) Current at $t = \tau$ (mA): _____ [mA] (d) Voltage at $t = \tau$ (V): _____ [V]

For the multi-loop circuit shown in the diagram containing two batteries (12.0 V and 3.00 V) and five resistors (3Ω , 4Ω , 5Ω , 12Ω , 24Ω):

Find the currents flowing through the 3Ω resistor, 4Ω resistor, 5Ω resistor, and 24Ω resistor:



SHOW WORK FOR ALL SUB-PARTS

Current through 3Ω resistor (A): _____ [A] Current through 4Ω resistor (A): _____ [A]
 Current through 5Ω resistor (A): _____ [A] Current through 24Ω resistor (A): _____ [A]

Three resistors ($R_1 = 2.50 \text{ k}\Omega$, $R_2 = 3.50 \text{ k}\Omega$, $R_3 = 4.50 \text{ k}\Omega$) are connected to a 100 V DC power supply. What is the ratio of the total power delivered when connected in parallel to the total power delivered when connected in series ($\frac{P_{\text{parallel}}}{P_{\text{series}}}$)?

SHOW WORK • CALCULATIONS • FORMULAS

Final Answer: _____ [ratio]

CONCEPTUAL Conceptual Trap #1 — Equipotential Surfaces & Conservative Field Work

Ch 7: Electric Potential

An electric field in a region is highly non-uniform, with strongly curved equipotential surfaces. A test charge q is transported from point A to point B along an intricate, winding path. Points A and B are both located on the exact same equipotential surface $V = 50 \text{ V}$, but along the path the particle traverses regions where the potential reaches $+500 \text{ V}$ and electric fields exceed 10^6 V/m . What is the net work done by the electrostatic field on the charge?

- ☐ (A) Zero, because the electrostatic field is conservative and depend only on initial and final potentials
- ☐ (B) Positive, because the particle traversed regions of much higher potential
- ☐ (C) Negative, because work was required to move against the strong 10^6 V/m electric fields
- ☐ (D) Cannot be determined without knowing the exact geometry and length of the winding path

WORKSPACE / REASONING

Selected Answer: **CONCEPTUAL Conceptual Trap #2** — Conductor Cavity Shielding with Off-Center Charge

Ch 7: Electric Potential

A neutral, solid conducting spherical shell of outer radius R_2 has an off-center spherical cavity of radius R_1 . A point charge $+q$ is placed inside the cavity, shifted away from the center. A second positive charge $+Q$ is placed outside the shell at distance $D > R_2$. Which statement correctly describes the electric field and charge distribution?

- ☐ (A) The outer charge $+Q$ experiences a force that depends on the exact off-center position of $+q$
- ☐ (B) The field inside the cavity is influenced by both $+q$ and the external charge $+Q$
- ☐ (C) The charge on the outer surface of the sphere is uniformly distributed regardless of where $+q$ is inside the cavity (if Q is removed)
- ☐ (D) The electric field inside the cavity at the center of the sphere is zero

WORKSPACE / REASONING

Selected Answer: **CONCEPTUAL Conceptual Trap #3** — Dielectric Insertion at Constant Voltage: Energy & Force

Ch 8: Capacitance & Dielectrics

A dielectric slab ($\kappa > 1$) is partially inserted between the plates of a parallel-plate capacitor that remains connected to an active, ideal battery ($V = \text{constant}$). As the slab enters the capacitor, what happens to the electrostatic force on the slab and the stored electrical energy?

- ☐ (A) The slab is pulled inward by an attractive fringing field force; stored energy increases
- ☐ (B) The slab is repelled outward; stored energy decreases
- ☐ (C) The slab experiences zero net force because voltage is held constant
- ☐ (D) The slab is pulled inward; stored energy remains constant because voltage is unchanged

WORKSPACE / REASONING

Selected Answer:

When a capacitor C is charged from zero to voltage $\mathcal{E}$ through a circuit with series resistance R , the battery supplies total energy $W_{\text{battery}} = Q\mathcal{E} = C\mathcal{E}^2$, but the capacitor stores only $U = \frac{1}{2}C\mathcal{E}^2$. Exactly 50% of the supplied energy is dissipated as heat in the resistor ($E_{\text{diss}} = \int I^2 R dt = \frac{1}{2}C\mathcal{E}^2$). If the resistor is replaced by a zero-resistance superconductor ($R \rightarrow 0$), what happens to the missing 50% of the energy?

- ☐ (A) The capacitor stores 100% of the energy ($U = C\mathcal{E}^2$)
- ☐ (B) The missing 50% is radiated away as electromagnetic waves and sparks due to rapid LC oscillations
- ☐ (C) Energy conservation is violated in ideal zero-resistance circuits
- ☐ (D) The battery only expends $\frac{1}{2} C\mathcal{E}^2$ from its chemical reserves

WORKSPACE / REASONING

Selected Answer:

When a household wall switch is flipped, a light bulb meters away lights up in less than 10^{-8} s. Yet the drift velocity of conduction electrons in the copper wire is only about $v_d \sim 10^{-4}$ m/s (sluggish snail's pace), while the random thermal/Fermi speed of the electrons is $v_F \sim 10^6$ m/s. What physical mechanism accounts for this near-instantaneous transmission of power?

- ☐ (A) Electrons at the switch push electrons forward like a solid incompressible rod
- ☐ (B) An electromagnetic wave propagating through the surrounding space/dielectric at near the speed of light establishes the electric field along the entire wire almost immediately
- ☐ (C) Electrons travel at the speed of light inside copper conductors
- ☐ (D) The high Fermi velocity pushes individual electrons rapidly into the bulb filament

WORKSPACE / REASONING

Selected Answer:

An incandescent light bulb with a tungsten filament has a temperature coefficient of resistivity $\alpha = +4.5 \times 10^{-3} \text{ }^\circ\text{C}^{-1}$. When glowing white-hot at steady state ($T \approx 2500^\circ\text{C}$), it draws 100 W at 120 V. At the cold instant the switch is first closed (room temperature $T_0 = 20^\circ\text{C}$), how does the cold inrush current compare to the normal steady-state operating current?

- ☐ (A) The initial inrush current is 10 to 15 times larger than steady-state current, which is why bulbs typically burn out at the moment they are switched on
- ☐ (B) The initial inrush current is much smaller than steady-state current because resistance is higher when cold
- ☐ (C) The current is exactly the same at all temperatures because the applied voltage is fixed at 120 V
- ☐ (D) The initial current is zero until the filament heats up to establish electron drift

WORKSPACE / REASONING

Selected Answer:

Twelve identical resistors of resistance R are soldered together along the twelve edges of a 3-dimensional cube. What is the equivalent resistance R_{eq} between two diametrically opposite corners across the main body diagonal?

- ☐ (A) $5/6 R$
- ☐ (B) $3/4 R$
- ☐ (C) $1/2 R$
- ☐ (D) $7/12 R$

WORKSPACE / REASONING

Selected Answer:

A parallel-plate capacitor is filled half with dielectric κ_1 and half with dielectric κ_2 . In Case A, the boundary is parallel to the plates (splitting thickness $d/2$ and $d/2$). In Case B, the boundary is perpendicular to the plates (splitting area $A/2$ and $A/2$). Which case yields higher capacitance, and what are their equivalent circuit models?

- ☐ (A) Case B yields higher capacitance; Case A is series while Case B is parallel
- ☐ (B) Case A yields higher capacitance; Case A is parallel while Case B is series
- ☐ (C) Both cases yield identical capacitance because each has exactly 50% volume of each dielectric
- ☐ (D) Case A yields higher capacitance because thickness d is halved

WORKSPACE / REASONING

Selected Answer:

You need to measure a very large resistance $R \approx 1.0 \text{ M}\Omega$ using a voltmeter with finite internal resistance $R_V = 10 \text{ M}\Omega$ and an ammeter with small internal resistance $R_A = 10 \Omega$. Which circuit configuration minimizes the fractional systematic measurement error?

- ☐ (A) Ammeter in series with R , and Voltmeter connected across BOTH the ammeter and R together
- ☐ (B) Voltmeter connected directly across R , with Ammeter measuring the combined current of R and the voltmeter
- ☐ (C) Either configuration gives identical loading error
- ☐ (D) An ammeter should never be used with a $1 \text{ M}\Omega$ resistor

WORKSPACE / REASONING

Selected Answer:

In a discharging RC circuit ($Q(t) = Q_0 e^{-t/\tau}$), the resistor dissipates stored electrical energy as heat. At what time t is the instantaneous rate of energy dissipation (power $P(t)$) equal to exactly half of its initial value P_0 ?

- ☐ (A) $t = \frac{1}{2} \tau \ln(2) \approx 0.347 \tau$
- ☐ (B) $t = \tau \ln(2) \approx 0.693 \tau$
- ☐ (C) $t = \tau$
- ☐ (D) $t = 2\tau \ln(2) \approx 1.386 \tau$

WORKSPACE / REASONING

Selected Answer:

A real DC battery has electromotive force $\mathcal{E}$ and constant internal resistance r . It is connected to a variable external load resistance R_L . Under what condition does the load resistor R_L dissipate maximum electrical power, and what is the electrical efficiency $\eta = \frac{P_{\text{load}}}{P_{\text{total}}}$ at that operating point?

- ☐ (A) $R_L = r$, and the electrical efficiency is exactly 50%
- ☐ (B) $R_L = 0$ (short circuit), and efficiency is 0%
- ☐ (C) $R_L \rightarrow \infty$ (open circuit), and efficiency is 100%
- ☐ (D) $R_L = 2r$, and the electrical efficiency is 67%

WORKSPACE / REASONING

Selected Answer:

Two real batteries are connected in a single loop with their positive terminals opposing each other: Battery 1 has $\mathcal{E}_1 = 12.0 \text{ V}$ and $r_1 = 2.0 \Omega$, while Battery 2 has $\mathcal{E}_2 = 6.0 \text{ V}$ and $r_2 = 1.0 \Omega$. An ideal voltmeter is placed across the terminals of Battery 2. What voltage does it read?

- ☐ (A) 8.0 V (terminal voltage is GREATER than EMF because it is being charged)
- ☐ (B) 4.0 V (terminal voltage is less than EMF)
- ☐ (C) 6.0 V (ideal voltmeter reads EMF directly)
- ☐ (D) 2.0 V (the difference between the two internal resistance drops)

WORKSPACE / REASONING

Selected Answer: