Last Name:________________ First Name__________________ Network-ID___________

Discussion Section:_________ Discussion TA Name:________________________________

Turn off your cell phone and put it out of sight.
Keep your calculator on your own desk. Calculators cannot be shared.
This is a closed book exam. You have ninety (90) minutes to complete it.

1. Use a #2 pencil. Do not use a mechanical pencil or pen. Darken each circle completely, but stay within the boundary. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner. Be especially careful that your mark covers the **center** of its circle.

2. You may find the version of **this Exam Booklet at the top of page 2**. Mark the version circle in the TEST FORM box near the middle of your answer sheet. **DO THIS NOW!**

3. Print your **NETWORK ID** in the designated spaces at the *right* side of the answer sheet, starting in the left most column, then **mark the corresponding circle** below each character. If there is a letter "o" in your NetID, be sure to mark the "o" circle and not the circle for the digit zero. If and only if there is a hyphen "-" in your NetID, mark the hyphen circle at the bottom of the column. When you have finished marking the circles corresponding to your NetID, check particularly that you have not marked two circles in any one of the columns.

4. Print **YOUR LAST NAME** in the designated spaces at the *left* side of the answer sheet, then mark the corresponding circle below each letter. Do the same for your **FIRST NAME INITIAL**.

5. Print your UIN# in the STUDENT NUMBER designated spaces and mark the corresponding circles. You need not write in or mark the circles in the SECTION box.

6. Sign your name **(DO NOT PRINT)** on the **STUDENT SIGNATURE** *line*.

7. On the **SECTION** *line*, print your **DISCUSSION SECTION**. You need not fill in the COURSE or INSTRUCTOR lines.

Before starting work, check to make sure that your test booklet is complete. You should have 17 ***numbered pages*** *plus three (3) Formula Sheets.*

Academic Integrity—**Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including dismissal from the University.**

This Exam Booklet is Version A. Mark the **A** circle in the **TEST FORM** box near the middle of your answer sheet. **DO THIS NOW!**

Exam Grading Policy—

The exam is worth a total of **122** points, composed of three types of questions.

MC5: *multiple-choice-five-answer questions, each worth 6 points.*
Partial credit will be granted as follows.

(a) If you mark only one answer and it is the correct answer,
you earn **6** points.
(b) If you mark *two* answers, one of which is the correct answer,
you earn **3** points.
(c) If you mark *three* answers, one of which is the correct answer,
you earn **2** points.
(d) If you mark no answers, or more than *three*, you earn 0 points.

MC3: *multiple-choice-three-answer questions, each worth 3 points.*
No partial credit.

(a) If you mark only one answer and it is the correct answer,
you earn **3** points.
(b) If you mark a wrong answer or no answers, you earn **0** points.

MC2: *multiple-choice-two-answer questions, each worth 2 points.*
No partial credit.

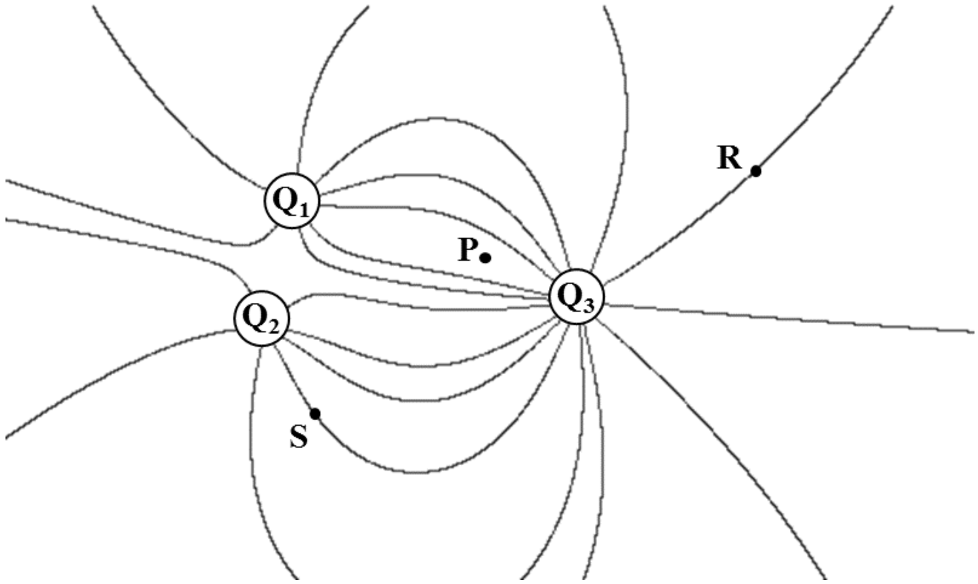
(a) If you mark only one answer and it is the correct answer,
you earn **2** points.
(b) If you mark the wrong answer or neither answer, you earn **0** points.

Some helpful information:

- A reminder about prefixes: p (pico) = 10^{-12}; n (nano) = 10^{-9}; μ (micro) = 10^{-6}; m (milli) = 10^{-3}; k (kilo) = 10^{+3}; M or Meg (mega) = 10^{+6}; G or Gig (giga) = 10^{+9}.

The next two questions pertain to the following situation:

Consider the electric field lines connecting the charged objects shown above.



1. Which of the following statements is correct?

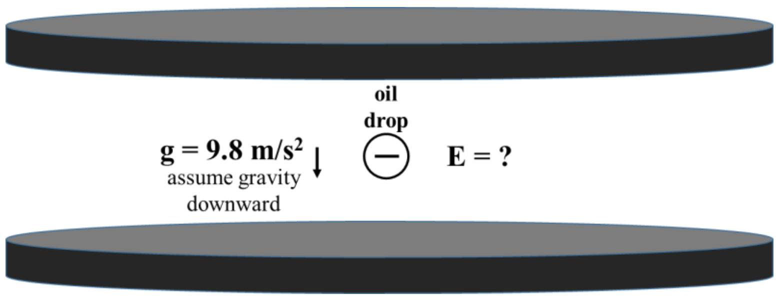
a. $|Q_1| < |Q_2|$
b. $|Q_1| < |Q_3|$
c. $|Q_3| < |Q_2|$

2. At which of the points P, R, or S labeled in the diagram would the smallest magnitude of electric field be measured?

a. P
b. R
c. S

The next two questions pertain to the following situation:

A large, negatively charged drop of oil is suspended in the electric field created by two charged capacitor plates near the earth's surface. Assume the object is suspended in the constant electric field between the plates, such that the pull of gravity is balanced by the electric force on the object.



3. Which plate must be the positively charged in order to cause the electric field to be oriented in the correct direction for the suspension to occur?

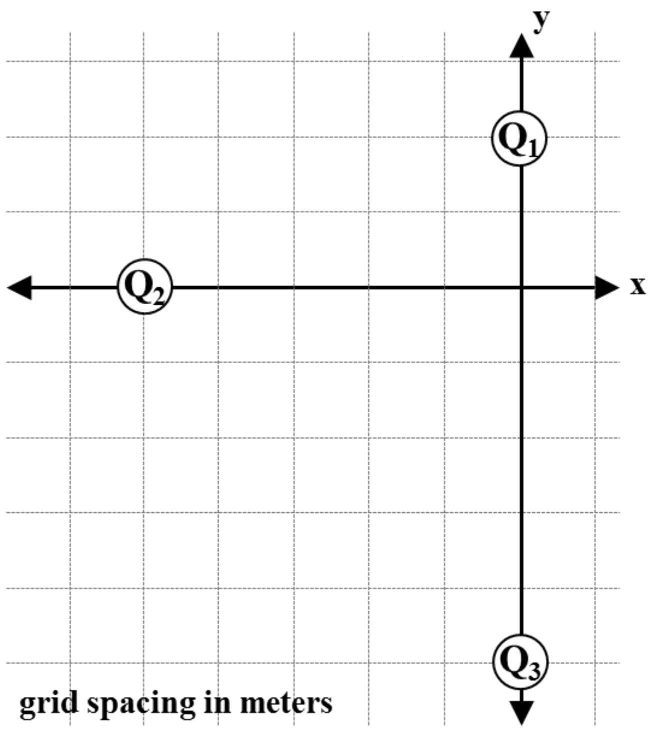
a. the top plate
b. the bottom plate
c. both plates

4. Given that the mass m of the charged object 4×10^{-13} kg and its charge Q is measured to be 8×10^{-18} C, what is the magnitude of the electric field E needed to cause such a suspension?

a. $E = 5.8 \times 10^{-4}$ N/C
b. $E = 3.4 \times 10^{3}$ N/C
c. $E = 4.9 \times 10^{5}$ N/C
d. $E = 6.2 \times 10^{6}$ N/C
e. $E = 9.7 \times 10^{9}$ N/C

The next two questions pertain to the following situation:

Three charges are placed in a coordinate system as shown and held in place. The charge Q_1 = +4 nC is located at (0 m, 2 m), the charge Q_2 = +7 nC is located at (–5 m, 0 m), and the charge Q_3 is located at (0 m, –5 m) with unknown charge.



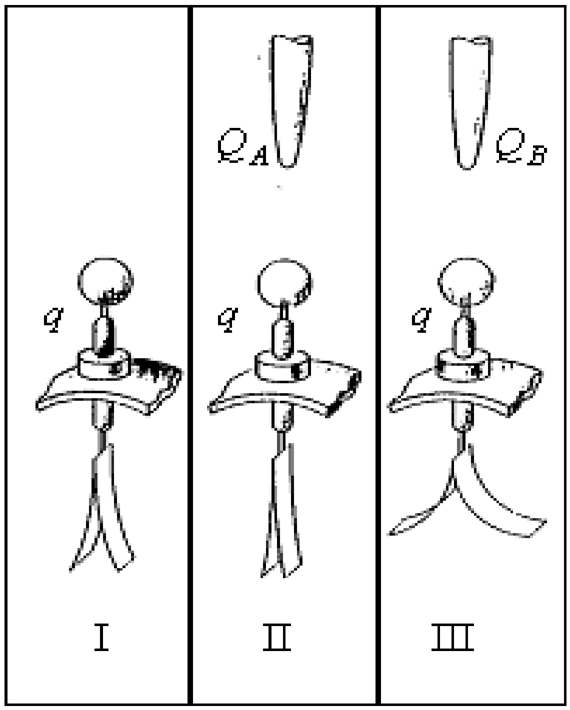
5. What must be the charge on Q_3 for the net force on Q_2 due to Q_1 and Q_3 to point directly to the left, in the $-x$ direction?

a. Q_3 = +6.5 nC
b. Q_3 = –9.1 nC
c. Q_3 = –0.78 nC
d. Q_3 = +3.6 nC
e. Q_3 = +17 nC

6. Let Q_2 be replaced with another charge $Q_{2,new}$ of the <u>same sign but larger in magnitude</u>. Q_3 is replaced with a new charge $Q_{3,new}$ such that $Q_{2,new}$ feels a net force only to the left, as above. How does $|Q_{3,new}|$ compare to $|Q_3|$ in the previous problem?

a. $|Q_{3,new}| < |Q_3|$
b. $|Q_{3,new}| = |Q_3|$
c. $|Q_{3,new}| > |Q_3|$

7. The conducting sphere of an electroscope is loaded with charge q so that the conducting leaves stand apart as shown in Figure I. As a rod with charge Q_A is brought near (but does not touch) the conducting sphere in figure II, the leaves move towards one another. This rod is removed and a different rod holding charge Q_B is brought near the conducting sphere in Figure III. The leaves are seen to move farther apart than in Figure I.

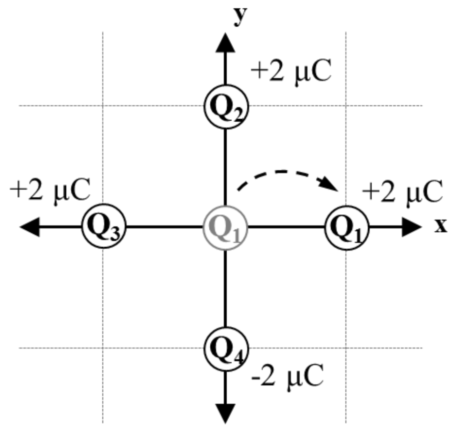


Which one of the following statements must be true?

a. The magnitude of Q_A must be less than the magnitude of q.
b. Q_A and q must have the same sign.
c. Q_B and q must have the same sign.
d. Q_A must be positive and Q_B must be negative.
e. Q_A must be negative and Q_B must be positive.

The next three questions pertain to the following situation:

Four charges of equal magnitude are arranged in the coordinate system as shown below. The charge Q_2 is located at (0 cm, 1 cm), the charge Q_3 at (–1 cm, 0 cm), and the charge Q_4 at (0 cm, –1 cm). Initially the charge Q_1 is located at the origin (0 cm, 0 cm) and you apply an external force to move the charge one centimeter in the +*x* direction to (1 cm, 0 cm). The values of the charges are indicated in the diagram.



grid spacing in centimeters

8. Calculate the potential at the origin for the charges in the final configuration.

a. $V(0,0) = 0$ V
b. $V(0,0) = -7.2 \times 10^6$ V
c. $V(0,0) = +1.4 \times 10^6$ V
d. $V(0,0) = -9.5 \times 10^5$ V
e. $V(0,0) = +3.6 \times 10^6$ V

9. How much work is done by your external force in moving Q_1 from the origin to its final position at (1 cm, 0 cm)?

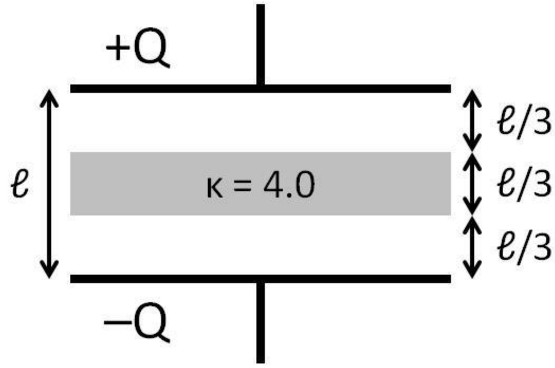
a. $W_{ext} = 0$ J
b. $W_{ext} = +1.8$ J
c. $W_{ext} = +3.6$ J
d. $W_{ext} = -1.8$ J
e. $W_{ext} = -9.2$ J

10. If the charge Q_1 were instead opposite in charge, the work done to move it as in the previous problem would have the same value but the opposite sign.

a. True
b. False

The next two questions pertain to the following situation:

An isolated capacitor consists of two parallel plates carrying charge $\pm Q$, separated by a distance ℓ. Its capacitance is C_0. Suppose a slab of dielectric material with dielectric constant $\kappa = 4.0$ and width $\ell/3$ is inserted midway between the two plates, as shown in the figure below.



11. In terms of C_0, what is the new capacitance C_{new} with the dielectric slab?

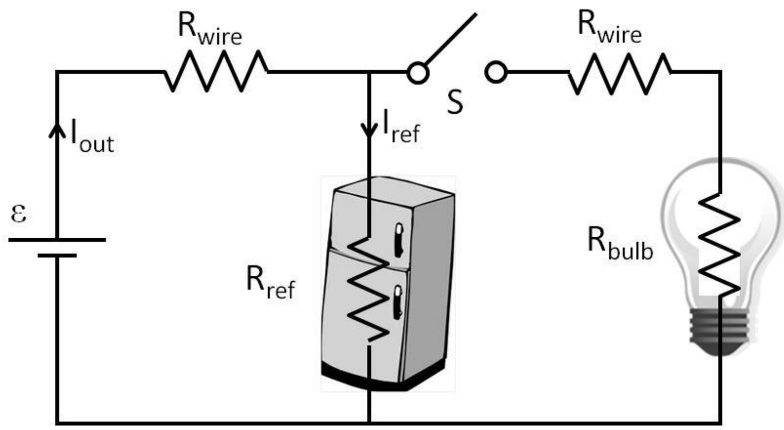
a. $C_{new} = 4C_0$
b. $C_{new} = 4/3C_0$
c. $C_{new} = C_0$
d. $C_{new} = 2/3C_0$
e. $C_{new} = 1/4C_0$

12. With the dielectric slab inserted, the charge Q on the plates

a. increases
b. decreases
c. remains the same

The next two questions pertain to the following situation:

The following represents a circuit in your kitchen. A wall outlet generates a voltage ε = 120 V and powers a refrigerator with resistance R_{ref} = 40 Ω. A light bulb in the room has resistance R_{bulb} = 200 Ω and can be turned on or off with the light switch S. The wires in the circuit have resistance R_{wire} = 20 Ω.



13. Let $I_{out,open}$ be the current out of the outlet when the light switch S is open (i.e when the light is *off*). Now the light switch S is closed, turning *on* the light. The current $I_{out,closed}$ out of the wall outlet

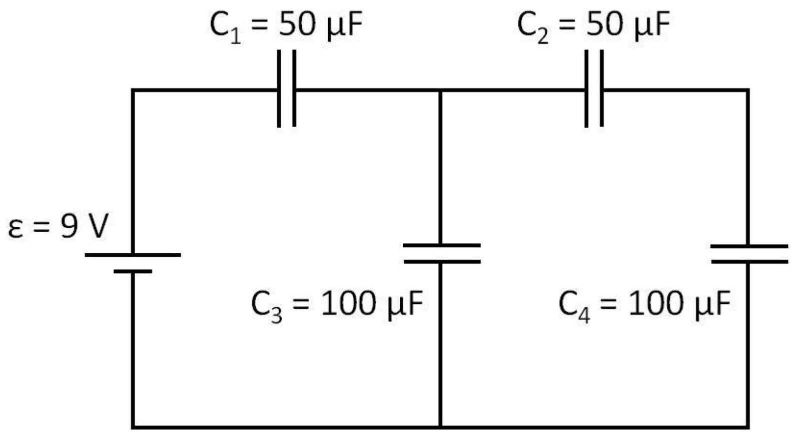
a. $I_{out,closed} > I_{out,open}$
b. $I_{out,closed} < I_{out,open}$
c. $I_{out,closed} = I_{out,open}$

14. What is the power P dissipated in the circuit when the switch is closed?

a. P = 175 W
b. P = 267 W
c. P = 486 W
d. P = 2210 W
e. $P = 7.93 \times 10^5$ W

The next two questions pertain to the following situation:

Consider a network of capacitors connected to a battery, as shown below. All the capacitors are fully charged.

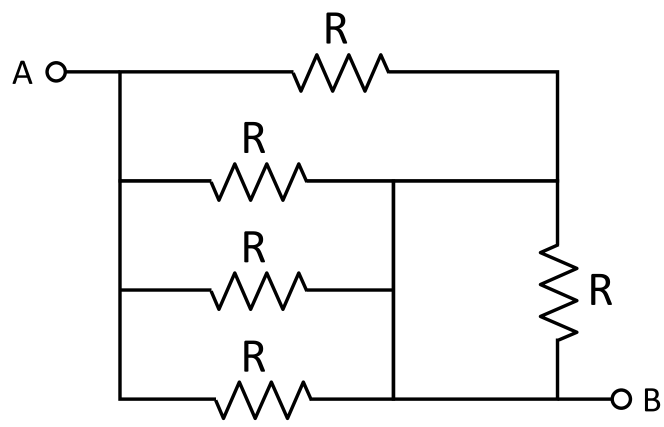


15. What is the total energy U_{tot} stored in the capacitor network?

a. U_{tot} = 0.850 mJ
b. U_{tot} = 3.115 mJ
c. U_{tot} = 1.472 mJ
d. U_{tot} = 7.257 mJ
e. U_{tot} = 10.58 mJ

16. What is the charge Q_3 stored on the capacitor C_3?

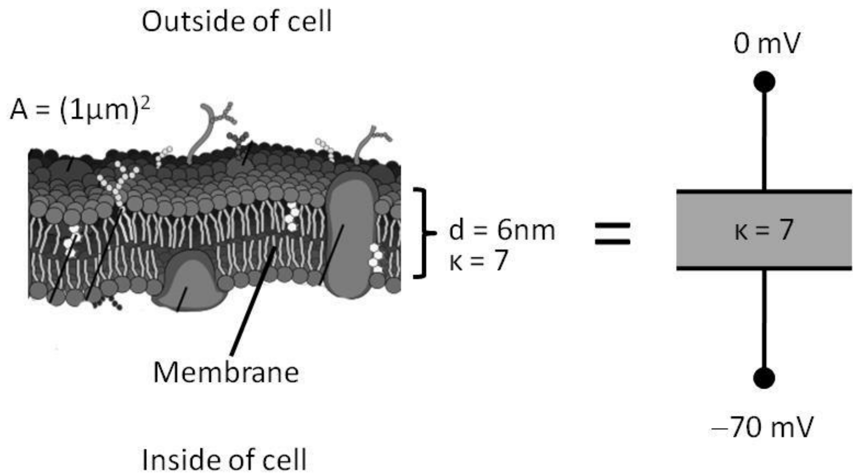
a. Q_3 = 245 μC
b. Q_3 = 350 μC
c. Q_3 = 492 μC



17. In the network of resistors above, the 5 resistors have the *same* resistance R. Calculate the equivalent resistance between points A and B in terms of R.

a. $R_{tot} = R/4$
b. $R_{tot} = 3R/5$
c. $R_{tot} = R$
d. $R_{tot} = 4R/3$
e. $R_{tot} = 5R/4$

18. A neuron can be modeled as a parallel plate capacitor, with the membrane acting as a dielectric and ions as charges on the plates. The membrane has a dielectric constant κ = 7.0 and a thickness d = 6.0 nm.



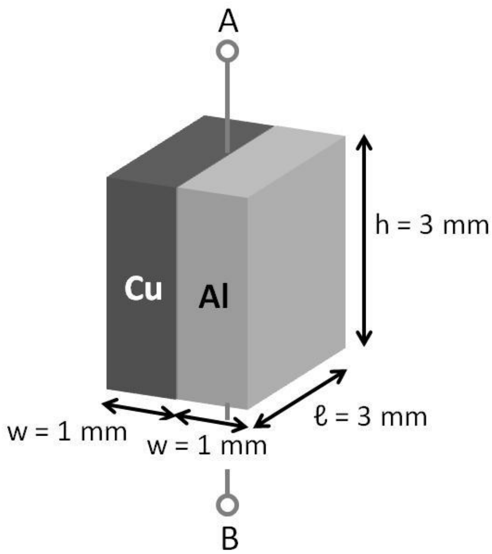
In its resting state, the inside of the cell is at a potential of –70mV relative to the outside because potassium (K^+) ions outside the cell exceed those inside.

Calculate the excess number of potassium ions (1 $K^+ = 1.6\times10^{-19}$ C) on the outer side of a 1-μm^2 patch of membrane.

a. $N = 4.5 \times 10^3$
b. $N = 9.3 \times 10^3$
c. $N = 2.6 \times 10^4$
d. $N = 7.4 \times 10^5$
e. $N = 1.2 \times 10^6$

A resistor is made from a slab of aluminum and a slab of copper pasted together as shown in the figure below.

The two slabs have identical dimensions: w = 1 mm, ℓ = 3 mm, and h = 3 mm. The resistivities of aluminum and copper are $\rho_{Al} = 2.65 \times 10^{-8}$ Ω·m and $\rho_{Cu} = 1.68 \times 10^{-8}$ Ω·m, respectively.

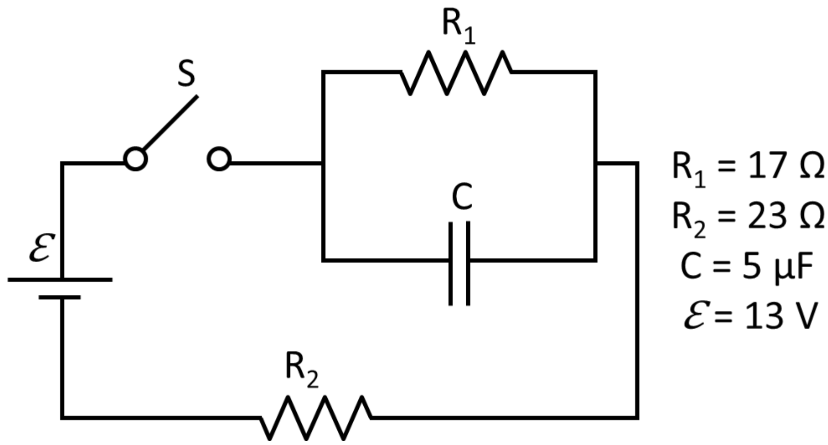


19. Suppose wires are attached to the top and bottom surfaces of the resistor, at positions A and B. What is the resistance measured across A and B?

a. $R_{A\text{-}B} = 0.48 \times 10^{-5}$ Ω
b. $R_{A\text{-}B} = 1.03 \times 10^{-5}$ Ω
c. $R_{A\text{-}B} = 6.74 \times 10^{-5}$ Ω

The next four questions pertain to the following situation:

Consider the following circuit. Initially the switch S is open and the capacitor C is fully discharged.

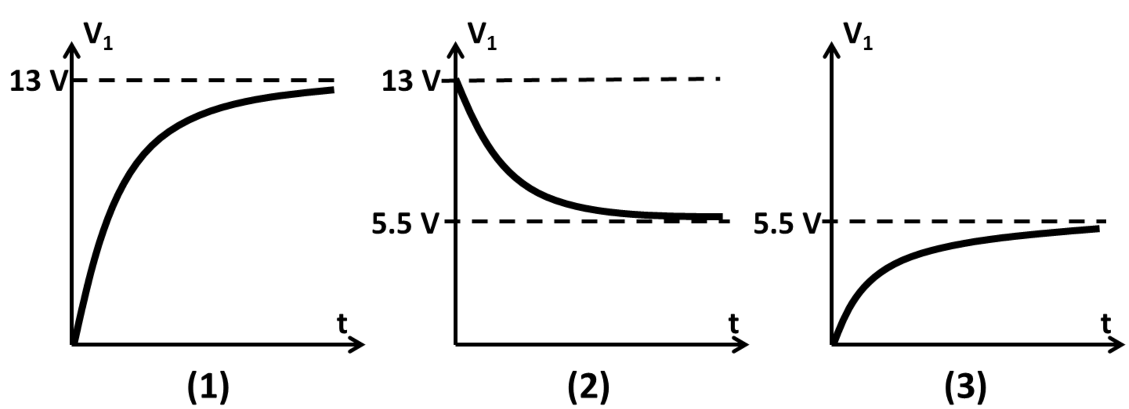


At $t = 0$, the switch is closed.

20. What is the current I_C through the capacitor C immediately after the switch is closed?

a. $I_C = 0$ A
b. $I_C = 0.355$ A
c. $I_C = 0.565$ A
d. $I_C = 0.705$ A
e. $I_C = 1.430$ A

21. Which of the following plots best represents the voltage drop V_1 across the resistor R_1 as a function of time?



a. (3)
b. (2)
c. (1)

(problem continues from previous page)

After a very long time, the switch S is now opened.

22. Immediately after the switch is opened, in which direction will the current flow through the capacitor?

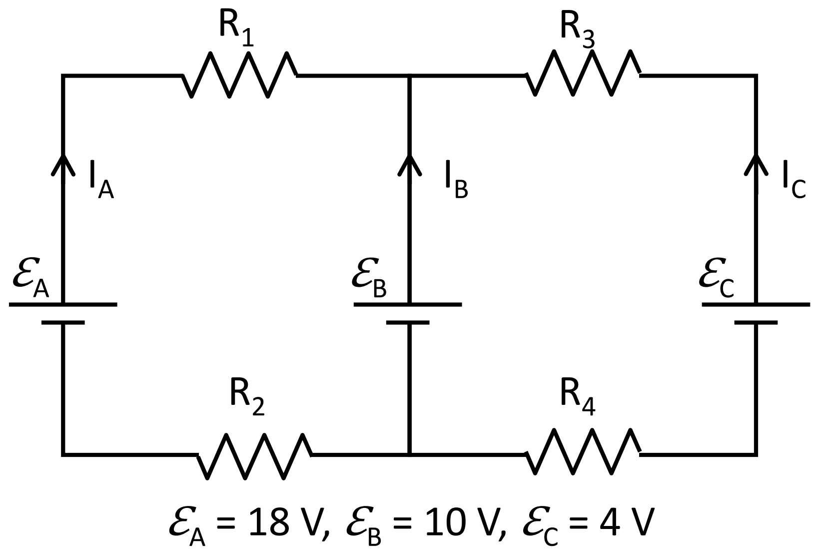
a. To the left
b. To the right
c. There is no current

23. How long will it take for the current across the capacitor to drop to 1/10 of the value just after the switch was opened?

a. 80.5 μs
b. 131 μs
c. 195 μs
d. 316 μs
e. 11.4 μs

The next two questions pertain to the following situation:

Consider the following circuit. All resistors have a resistance of 1 Ω.



24. What is the current I_A out of the battery with emf $\mathcal{E}_A$?

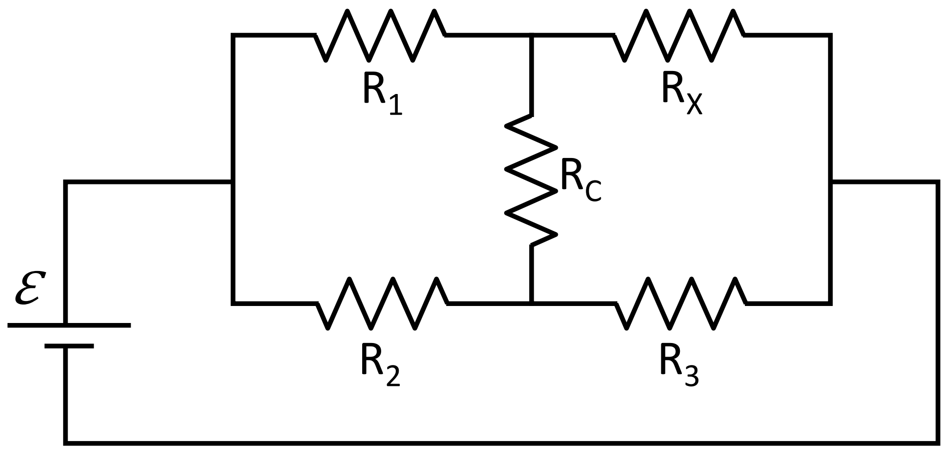
a. $I_A = 9$ A
b. $I_A = 4$ A
c. $I_A = 14$ A
d. $I_A = 3.5$ A
e. $I_A = 5$ A

25. If $\mathcal{E}_C$ is increased, the current across R_1 will:

a. increase
b. stay the same
c. decrease

The next two questions pertain to the following situation:

In the following circuit, the current through the resistor R_C is zero.



$R_1 = 10\ \Omega$; $R_2 = 20\ \Omega$; $R_3 = 30\ \Omega$; $\mathcal{E} = 12$ V

26. What is the current through resistor R_3?

a. 1.0 A
b. 0.48 A
c. 0.24 A
d. 2.2 A
e. 3.7 A

27. What is the value of R_x?

a. 30 Ω
b. 15 Ω
c. 10 Ω

Check to make sure you bubbled in all your answers.
Did you bubble in your name, exam version and network-ID?

Mechanics:

$x = x_0 + v_0 t + \frac{1}{2}at^2$ $v = v_0 + at$ $F = ma$ $a_c = \frac{v^2}{r}$

$E_{tot} = K.E. + P.E.$ $K.E. = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ $p = mv$ $W_F = Fd\cos\theta$

Electrostatics:

$F_{12} = \frac{kq_1q_2}{r^2}$ $E \equiv \frac{F}{q_0}$ $V \equiv \frac{U}{q_0}$ Point charge: $E = \frac{kq}{r^2}$, $V = \frac{kq}{r}$

$U_{12} = \frac{kq_1q_2}{r}$ $W_E = -\Delta U = -W_{you}$

Capacitance:

$C \equiv \frac{Q}{V}$ Parallel plate capacitor: $C = \frac{\kappa\varepsilon_0 A}{d}$, $V = Ed$

$U_C = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$ $C_P = C_1 + C_2 + \cdots$ $\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$

Resistance:

$R \equiv \frac{V}{I}$ $I = \frac{\Delta q}{\Delta t}$ Physical resistance: $R = \rho\frac{L}{A}$

$P = IV = I^2R = \frac{V^2}{R}$ $R_S = R_1 + R_2 + \cdots$ $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

Circuits:

$\sum \Delta V = 0$ $\sum I_{in} = \sum I_{out}$

$q(t) = q_\infty(1 - e^{-t/\tau})$ $q(t) = q_0 e^{-t/\tau}$ $I(t) = I_0 e^{-t/\tau}$ $\tau = RC$

Magnetism:

$F = qvB\sin\theta$ $r = \frac{mv}{qB}$ $F = ILB\sin\theta$ $\tau = NIAB\sin\varphi$

$B_{wire} = \frac{\mu_0 I}{2\pi r}$ $B_{sol} = \mu_0 nI$

Induction and inductance:

$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$ $\Phi = BA\cos\varphi$

$\varepsilon_{bar} = BLv$ $\varepsilon_{gen} = \varepsilon_{max}\sin\omega t = \omega NAB\sin\omega t$ $\omega = 2\pi f$

$L \equiv \frac{N\Phi}{I}$ $\varepsilon = -L\frac{\Delta I}{\Delta t}$ Solenoid inductor: $L = \mu_0 n^2 A\ell$ $U_L = \frac{1}{2}LI^2$

AC circuits and transformers:

$V_{rms} = \frac{V_{max}}{\sqrt{2}}$ $I_{rms} = \frac{I_{max}}{\sqrt{2}}$ $\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$

$V_R(t) = V_{R,max}\sin(\omega t) = I_{max}R\sin(\omega t)$ $\omega = 2\pi f$

$V_C(t) = V_{C,max}\sin(\omega t - \pi/2) = I_{max}X_C\sin(\omega t - \pi/2)$ $X_C \equiv \frac{1}{\omega C}$

$V_L(t) = V_{L,max}\sin(\omega t + \pi/2) = I_{max}X_L\sin(\omega t + \pi/2)$ $X_L \equiv \omega L$

$V_{gen}(t) = V_{gen,max}\sin(\omega t + \varphi) = I_{max}Z\sin(\omega t + \varphi)$ $Z \equiv \sqrt{R^2 + (X_L - X_C)^2}$ $\tan\varphi = \frac{X_L - X_C}{R}$

$\overline{P} = I_{rms}V_{R,rms} = I_{rms}V_{gen,rms}\cos\varphi$ $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Electromagnetic waves:

$\lambda = \frac{c}{f}$ $E = cB$

$u_E = \frac{1}{2}\varepsilon_0 E^2$ $u_B = \frac{1}{2\mu_0}B^2$ $\bar{u} = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0}B_{rms}^2 = \varepsilon_0 E_{rms}^2 = \frac{B_{rms}^2}{\mu_0}$ $S = I = \bar{u}c$

$f' = f\left(1 \pm \frac{u}{c}\right)$ $I = I_0\cos^2\theta$

Reflection and refraction:

$\theta_r = \theta_i$ $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$n_1\sin\theta_1 = n_2\sin\theta_2$ $v = \frac{c}{n}$ $\sin\theta_c = \frac{n_2}{n_1}$ $M = \frac{\theta'}{\theta} \approx \frac{d_{near}}{f}$

Interference and diffraction:

Double slit interference: $d\sin\theta = m\lambda$ $d\sin\theta = (m + \frac{1}{2})\lambda$ $m = 0, \pm 1, \pm 2\ldots$

Single-slit diffraction: $w\sin\theta = m\lambda$ $m = \pm 1, \pm 2\ldots$

Circular aperture: $D\sin\theta \approx 1.22\lambda$

Thin film: $\delta_1 = (0 \text{ or } \frac{1}{2})$ $\delta_2 = (0 \text{ or } \frac{1}{2}) + 2t\frac{n_{film}}{\lambda_0}$ $|\delta_2 - \delta_1| = (m \text{ or } m + \frac{1}{2})$ $m = 0, 1, 2\ldots$

Quantum mechanics:

$E = hf = \frac{hc}{\lambda}$ $\lambda = \frac{h}{p}$

Blackbody radiation: $\lambda_{max}T = 2.898\times 10^{-3}\, m\cdot K$ Photoelectric effect: $K.E. = hf - W_0$

$\Delta p_x \Delta x \geq \frac{\hbar}{2}$ $\hbar \equiv \frac{h}{2\pi}$

Bohr atom: $2\pi r_n = n\lambda \qquad n = 1, 2, 3\ldots$ $\qquad L_n = mv_n r_n = n\hbar$

$r_n = \left(\frac{\hbar^2}{mke^2}\right)\frac{n^2}{Z} \approx (5.29\times10^{-11} m)\frac{n^2}{Z}$ $\qquad E_n = -\left(\frac{mk^2e^4}{2\hbar^2}\right)\frac{Z^2}{n^2} \approx -(13.6 eV)\frac{Z^2}{n^2}$

$\frac{1}{\lambda} \approx (1.097\times10^7 m^{-1})\, Z^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

Quantum atom: $L = \sqrt{\ell(\ell+1)}\hbar$ $\qquad L_z = m_\ell \hbar$

Nuclear physics and radioactive decay:

$A = Z + N$ $\qquad r \approx (1.2\times10^{-15} m)A^{1/3}$ $\qquad E_0 = mc^2$

$\frac{\Delta N}{\Delta t} = -\lambda N$ $\qquad N(t) = N_0 e^{-\lambda t} = N_0 2^{-t/T_{1/2}}$ $\qquad T_{1/2} \equiv \frac{\ln 2}{\lambda} \approx \frac{0.693}{\lambda}$

Special relativity:

$\Delta t = \gamma \Delta t_0$ $\qquad L = \frac{L_0}{\gamma}$ $\qquad \gamma \equiv \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

Constants and unit conversions:

$g = 9.8 m/s^2$ $\qquad e = 1.60\times10^{-19} C$

$\varepsilon_0 = 8.85\times10^{-12} C^2/Nm^2$ $\qquad k \equiv \frac{1}{4\pi\varepsilon_0} = 8.99\times10^9 Nm^2/C^2$ $\qquad \mu_0 = 4\pi\times10^{-7} T\cdot m/A$

$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = 3\times10^8 m/s$ $\qquad h = 6.626\times10^{-34} J\cdot s$ $\qquad hc = 1240 nm\cdot eV$

$1eV = 1.60\times10^{-19} J$ $\qquad m_{proton} = 1.67\times10^{-27} kg = 938 MeV$ $\qquad m_{electron} = 9.11\times10^{-31} kg = 511 keV$

SI Prefixes

Power	**Prefix**	**Symbol**
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^0	—	—
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p