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. **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!**

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 18 **numbered pages** *plus three 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.**

Exam Grading Policy—

The exam is worth a total of **126** 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 following situation pertains to the next two questions:

As shown in the diagram below, a circuit is constructed consisting of two batteries with emf ε_1 and ε_2 and resistors with resistance R_1, R_2, and R_3. Two currents I_1 and I_2 are labeled on the diagram.

Kirchhoff's votage law

down   down
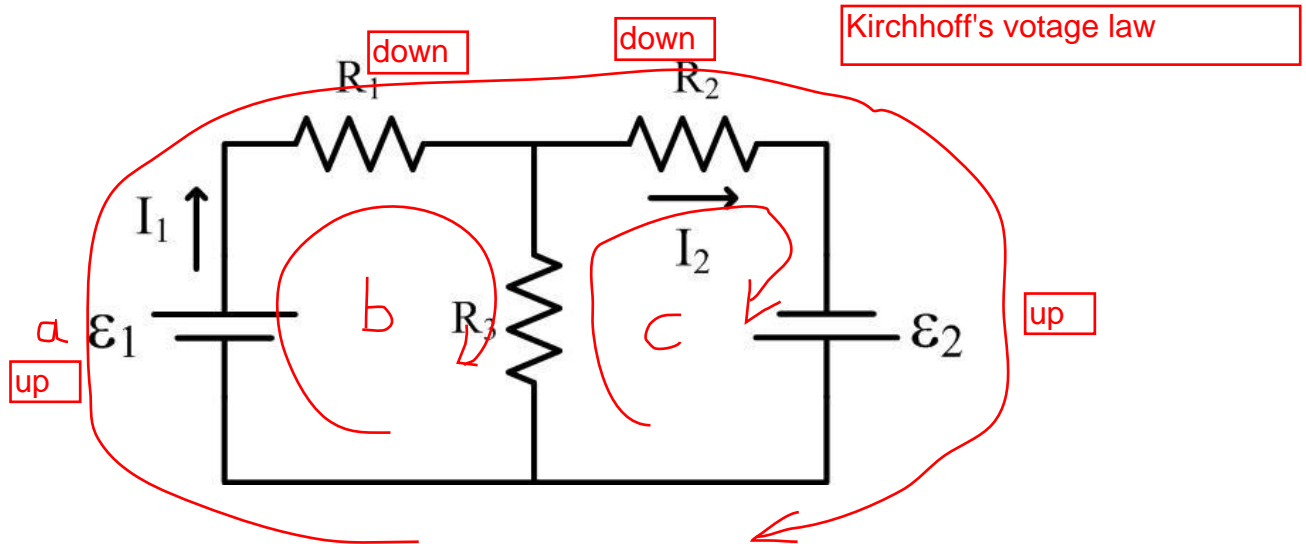
E1 - I1R1 - I2R2 + E2 = 0.

1. Which equation is a correct application of Kirchhoff's laws?

a. $\varepsilon_1-I_1R_1-I_2R_2+\varepsilon_2=0$
b. $\varepsilon_1+I_1R_1+I_2R_2+\varepsilon_2=0$
c. $\varepsilon_1+I_1R_1-I_2R_2=0$

2. Which equation is another correct application of Kirchhoff's laws?

a. $\varepsilon_2-(I_1-I_2)R_3=0$
b. $\varepsilon_1-I_1R_1-(I_1-I_2)R_3=0$
c. $\varepsilon_1-I_1R_1-(I_1+I_2)R_3=0$
d. $\varepsilon_2+(I_1-I_2)R_3+I_2R_2=0$
e. $\varepsilon_2+(I_1+I_2)R_3+I_2R_2=0$

These formulas are about loops including only one electric cell.

Around b: E1 - I1R1 - R3(I1 - I2) = 0

Around c: R3(I1-I2) - I2R2 + E2 = 0

3. What is the resistance between points A and B of the resistor network shown in the diagram below? Each resistor in the network has resistance R.

Series and parallel connection

R

A

R

R
series
= 2R

parallel
= 2R^2/3R =(2/3)R

R

B
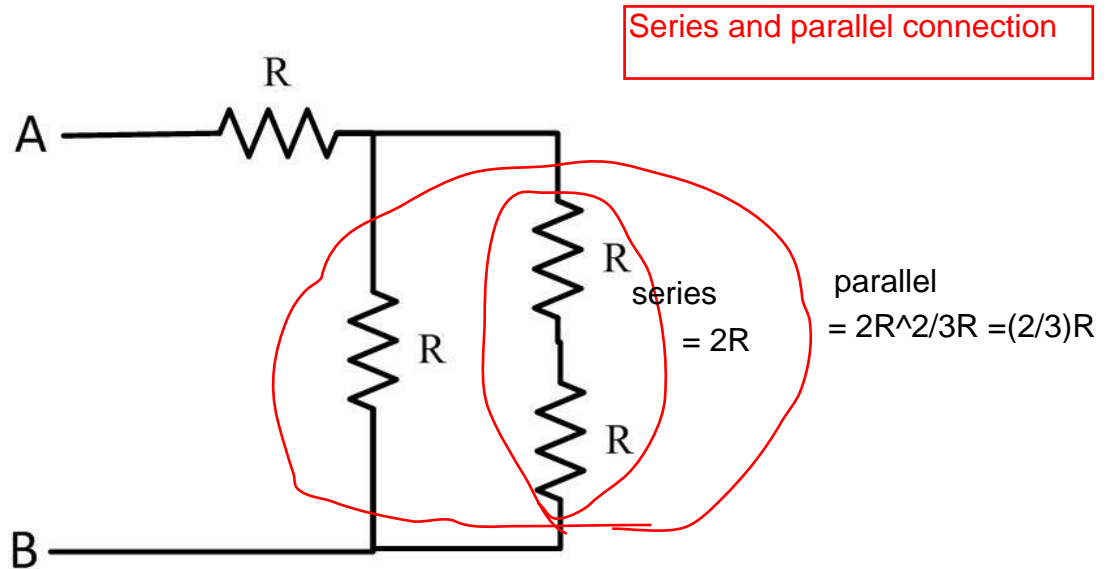
a. 5R/2
b. 3R/5
c. 5R/3
d. 4 R
e. R/4

Rtot = R + (2/3)R = (5/3)R

4. Animal fat has a resistivity ρ=7 Ω·m. What is the resistance of a cylinder of animal fat that has a radius of 0.5 m and a length of 1 m?

a. 0.79 Ω
b. 0.0079 Ω
c. 1.6 Ω
d. 12500 Ω
e. 8.9 Ω

R = ¥rho L/A = 7 x 1/(¥pi x 0.5^2) = 8.912 ohm

The following situation pertains to the next four questions:

The circuit in the diagram below consists of a 5V battery, a 6 μF capacitor, and a 5Ω, 20 Ω, and 10 Ω resistor. The switches A and B are initially open, and the capacitor is initially uncharged

A   B

5 V   6 μF   5 Ω   20 Ω

parallel
= 5x20/25 = 4 ohm

10Ω

5. Switch A is closed at time t=0 and switch B is left open. Which graph shown below best represents how the voltage V_C across the capacitor changes with time t?   Initially, C is not charged, so voltage at a and that at b are the same, so the equivalent circuit looks as

V_C

5 V

t

.a

V_C

5 V

t

b

V_C

5 V

t

c

a. a
b. b
c. c

After a long time, C is charged up to 5V.

6. After closing switch A and waiting a long time, what is the charge on the capacitor?

a. 0 C
b. 1.2 μC
c. 30 μC

The voltage across the capacitor is 5 V, so
    Q = 5C = 30 ¥muC

The next two questions refer to the diagram on the previous page:

7. After closing switch A and waiting a long time, what is the current through the 10 Ω resistor?

a. 0.5 A

a = 5 V and b = 0, so there is no voltage across the resistor. 0 A.

b. 0 A

c. 2 A

8. After switch A has been closed for a long time, switch A is opened and switch B is closed. Which graph best represents how the current I through the 5 Ω resistor changes with time after switch B is closed?
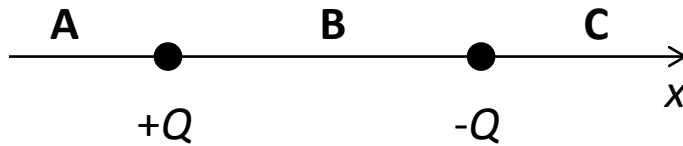
Initially, the voltage across C is 5 V, so 5/4 A flows through switch B.
(5/4) x (4/5) = 1 A goes through 5 ohm.
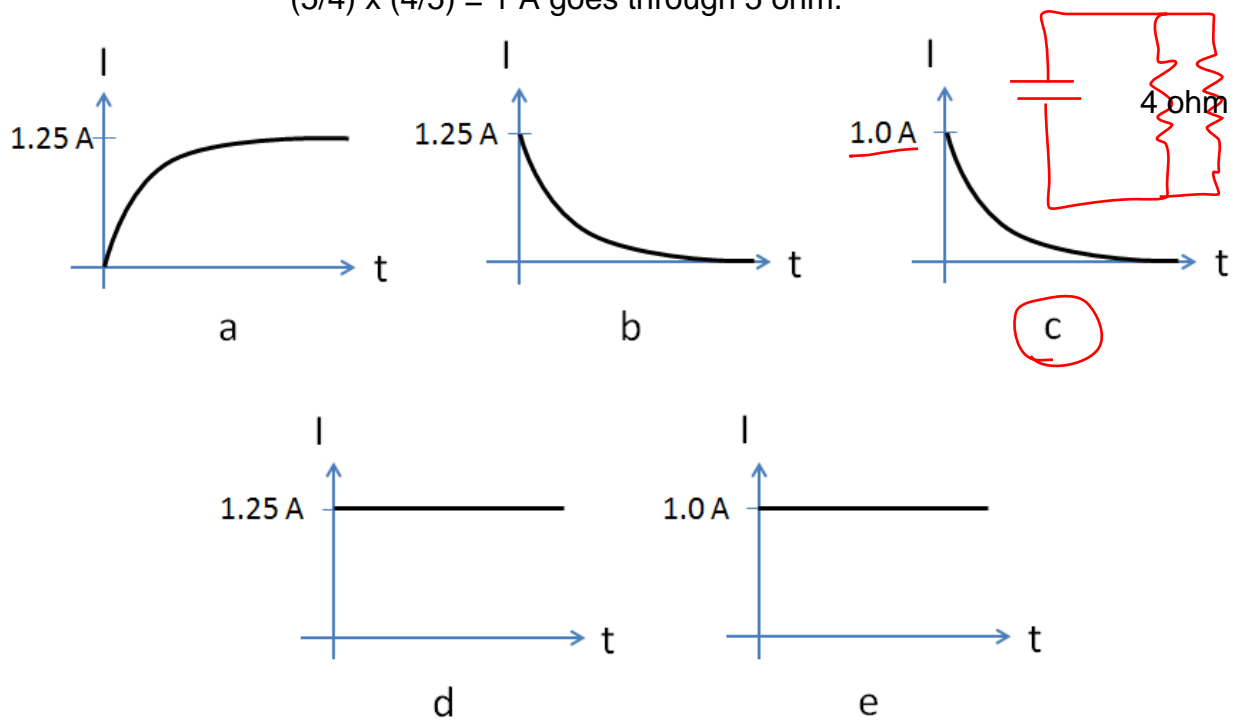
a. a

b. b

c. c

d. d

e. e

9. Two charges, $+Q$ and $-Q$, are placed on the x-axis as shown. In which of the three regions, **A**, **B**, and **C**, on the x-axis can the electric field be zero?

a. Region **A**
b. Region **B**
c. Region **C**
d. Regions **A** and **C**
e. No regions.

A   **B**   **C**

●   ●

$+Q$ $-Q$

X

0 only at infinity.

Superposition principle

Draw E fields due to individual charges.

10. Four charges, all ± 4 μC, are placed at the corners of a square with 0.15 m long sides, as shown. Calculate the x-component, E_x, of the electric field at the center of the square.

y

$+4$ μC

0.15 m

a. $E_x = -6.4 \times 10^6$ N/C
b. $E_x = -3.2 \times 10^6$ N/C
c. $E_x = \quad\quad 0$ N/C
d. $E_x = +3.2 \times 10^6$ N/C
e. $E_x = +6.4 \times 10^6$ N/C

-4 μC   0.15/¥sqrt{2} $+4$ μC

x
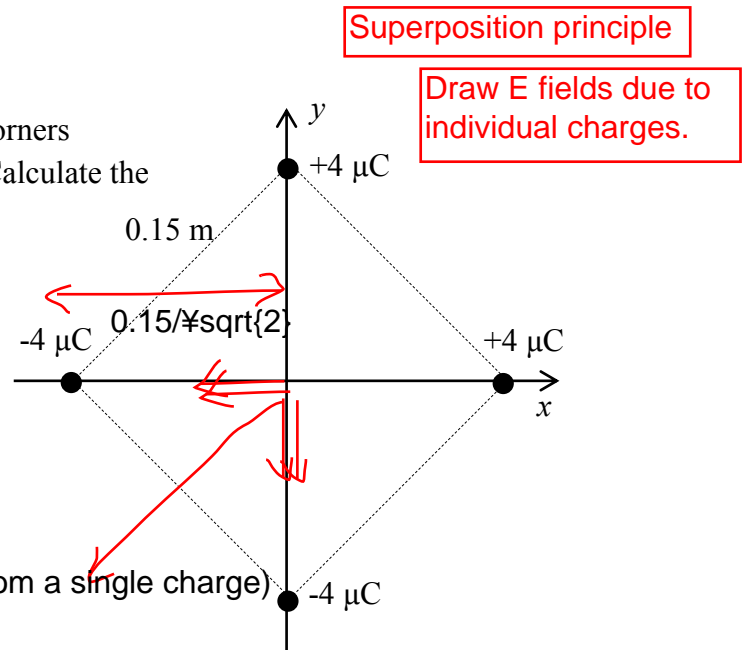
The length of one arrow (= contribution from a single charge) is

-4 μC

$|E| = kQ/r^2 = (9 \times 10^{9}) (4 \times 10^{-6})/(0.15/sqrt\{2\})^2$
     $= 3200 \times 10^{9 - 6} = 3.2 \times 10^6$.
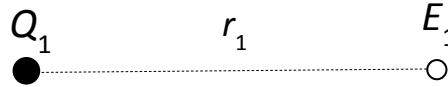
Therefore, the x components is -2 times $|E| = -6.4 \times 10^6$ N/C.

11. Compare the magnitudes of the electric fields, E_1 and E_2, produced by two charges, $Q_1 = 3.2$ µC and $Q_2 = 0.75$ µC. We measure E_1 a distance $r_1 = 0.2$ m from Q_1, and E_2 a distance $r_2 = 0.1$ m from Q_2. Which is larger, E_1 or E_2?

a. E_1 is larger.
b. E_1 and E_2 are equal.
c. E_2 is larger.
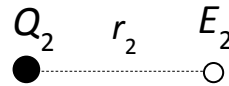
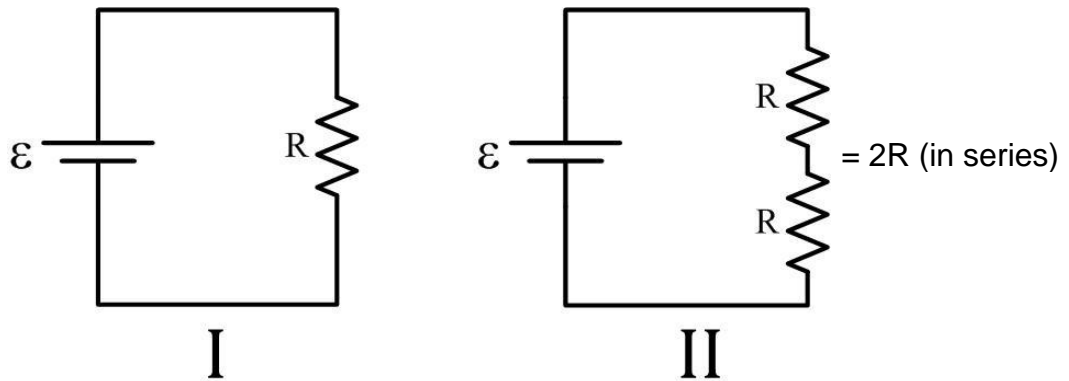We compare kQ/r^2, so we have only to compare Q/r^2.
For 1 this is 3.2/(0.2^2) = 80
For 2 this is 0.75/(0.1^2) = 75. 1 wins.

12. Consider the two circuits, labeled I and II, in the circuit below. All resistors have the same resistance R, and the batteries both have the same emf ε.

= 2R (in series)

I   II

Which of the following statements is true regarding the power P_I supplied by the battery in circuit I compared with the power P_{II} supplied by the battery in circuit II?

a. $P_I = 2 P_{II}$
b. $P_I = 0.5 P_{II}$
c. $P_I = 0.25 P_{II}$
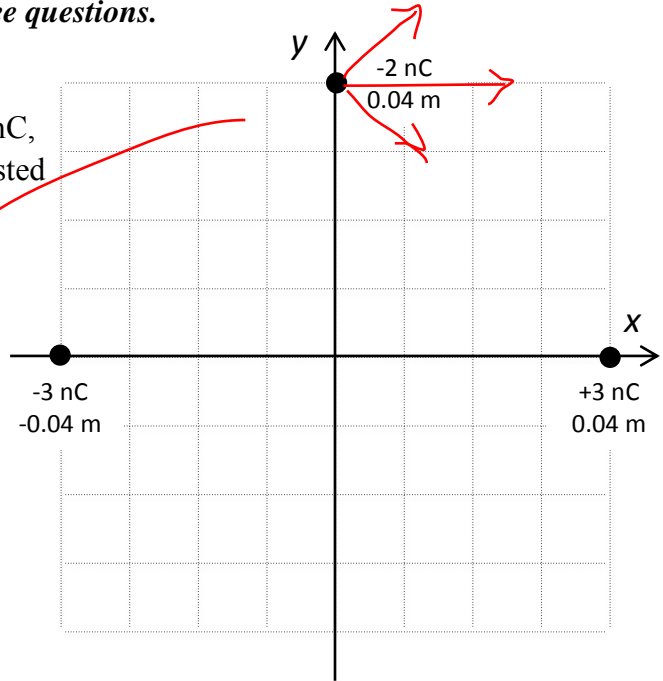d. $P_I = 4 P_{II}$
e. $P_I = P_{II}$

P = V^2/R

I: P1 = V^2/R
II: P2 = V^2/(2R) = P1/2.

Sketch the forces.

The following situation pertains to the next three questions.

A positive charge, +3nC is placed
at +0.04 m on the *x*-axis. A negative charge, -3 nC,
is placed at -0.04 m on the x-axis. We are interested
in the electric force on a -2 nC charge placed at
+0.04 m on the *y*-axis.

13. What is the direction of the electric force
on the -2 nC particle?

a. In the +*x* direction.
b. In the -*x* direction.
c. In the +*y* direction.
d. In the -*y* direction.
e. The force is zero.

14. What is the magnitude of the electric force on the -2 nC particle?

a.   0 N
b.   2.4 N
c. 3.6×10^{-5} N
d. 2.4×10^{-5} N
e. 4.8×10^{-5} N

There are two forces:
   one of them $|F| = k\, Q1\,Q2/r^2$
      $= (9 \times 10^9)\,(2 \times 10^{-9})\,(3 \times 10^{-9})/(32 \times 10^{-4})$
      $= 1.69 \times 10^{9 - 9 - 9 + 4} = 1.69 \times 10^{-5}$ N
This times $\sqrt{2} = 2.39 \times 10^{-5}$ N is the total force intensity.

15. What is the electric potential at the position of the -2 nC particle, due to the two charges on
the *x*-axis? The electric potential is defined to be zero at infinity.

a. -955 V
b. -477 V
c.   0 V
d.   477 V
e.   955 V

+ and - charges of identical magnitudes are at the same lengths,
so their contribution to the electric potential cancel each other.

The following two problems are related.

16. How much work must you do to assemble the charge configuration shown? All three charges have $Q = -1.5$ µC and are equally spaced ($d = 0.035$ m) on the *x*-axis.

a.   1.16 J
b.   1.45 J
c.   1.74 J
d. 9.64×10^5 J
e. 1.16×10^6 J

$\leftarrow\!\!-\ d\ -\!\!\rightarrow\!\!\leftarrow\!\!-\ d\ -\!\!\rightarrow$

(three charges Q Q Q on the *x*-axis)
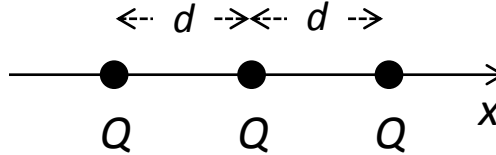
We have only to compute the total potential energy of the system:
kQ^2(1/d + 1/d + 1/2d) = (5/2)kQ^2/d
= (5/2) (9x10^9) (1.5x10^{-6})^2/(0.035)
= 1446.42 x 10^{9 - 6} = 1.45 J

17. Suppose the charges in the previous problem all had $Q = +1.5$ µC. How would your answer change?

Q^2 matters, so no change.

a. The work would become less positive (or more negative).
b. The work would not change.
c. The work would become more positive (or less negative).

18. A small particle of mass $m = 4 \times 10^{-18}$ kg has a charge of $q = -1.6 \times 10^{-19}$ C. It is placed in a vertical electric field, *E*, as shown. What must the magnitude of *E* be to suspend the particle against the force of gravity?

a.   0.04 N/C
b.   25 N/C
c.   245 N/C

electric force

E

gravity

$m = 4 \times 10^{-18}$ kg
$q = -1.6 \times 10^{-19}$ C
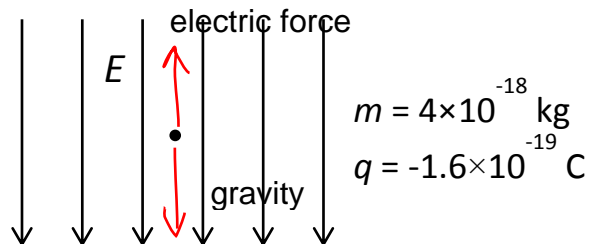
The force balance problem:
    gravity: mg
    electric force: Eq
so
    mg = Eq -> E = mg/q = 4x10^{-18}x9.8/(1.6x10^{-19})
        = 24.5 x 10^{-18+19} = 245 N/C.

The next two problems refer to the capacitor network shown below.

The circuit consists of 4 capacitors C_1, C_2, C_3 and C_4 and a battery with a voltage of 9 V. All capacitors have identical values $C = C_1 = C_2 = C_3 = C_4$.

C_1

= 2C^2/3C=(2/3)C

$V = 9V$

C_2

= (2/3)C + C = (5/3)C.

C_3

C_4

= 2C (in parallel)
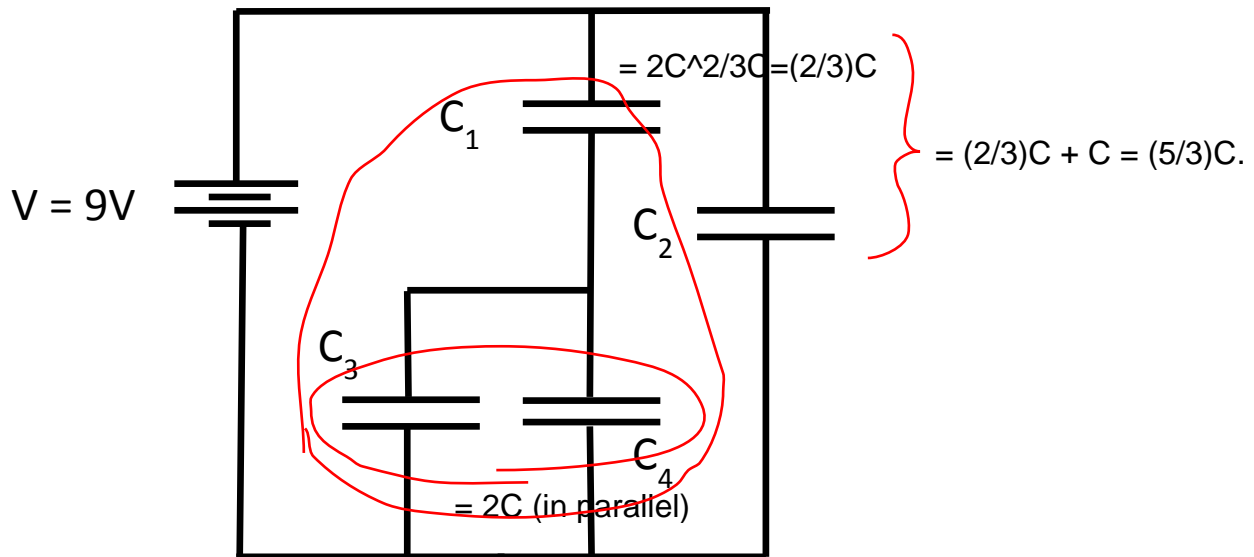
19. What is the equivalent capacitance C_{eq} of the circuit in terms of $C=C_1=C_2=C_3=C_4$?
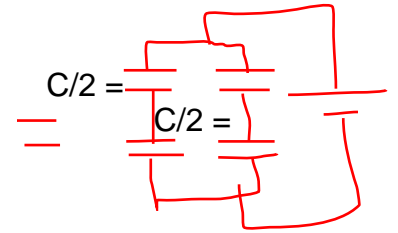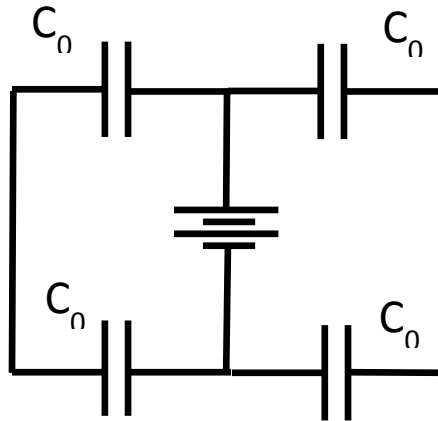
a.   C/3
b.   2C/3
c.   5C/3
d.   7C/3
e.   3C

20. If $C = 15$ mF, what is the electric charge Q_2 stored in capacitor C_2 ?

The voltage across C2 is 9V, so Q = 9 x (15 x10^{-3}) = 135 x 10^{-3} C.

a. 0.045 C
b. 0.135 C
c. 0.225 C

21. A circuit has 4 capacitors of equal capacitance $C_0 = 20$ μF. What is the equivalent capacitance C_{eq} of the circuit?

a. $C_{eq} = 10$μ F
b. $C_{eq} = 20$μ F
c. $C_{eq} = 30$μ F
d. $C_{eq} = 40$μ F
e. $C_{eq} = 50$μ F

C/2 =
C/2 =

C/2 + C/2 = C is the total capacitance.

22. Two capacitors are made from two square sheets of copper plates. For each of the capacitors the length of the sides of the sheets is identical to the distance between the two plates. The distances between plates for the first capacitor with capacitance C_1 is d_1, and $d_2=2d_1$. What is the capacitance C_2 in terms of C_1 ?

bad or wrong question

$C = ¥epsilon0 \, A/d$

a. $C_2=C_1/2$
b. $C_2=C_1$
c. $C_2=2C_1$

$d_2 = 2d_1$
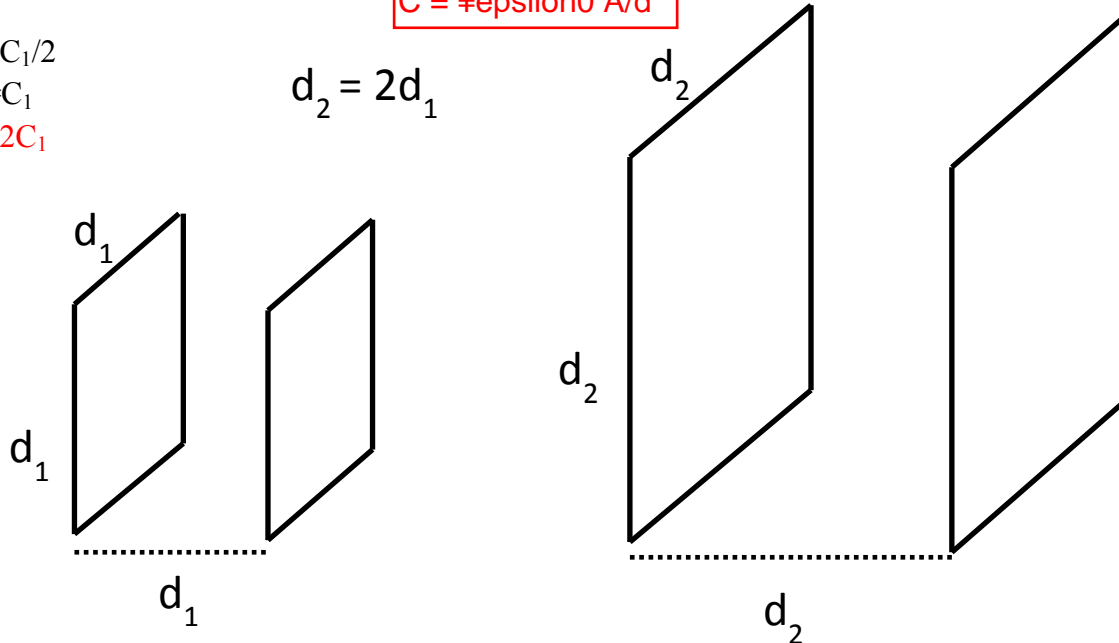
C1 = ¥espilon0 d^2/d, C2 = ¥epsilon0 (2d)^2/(2d) = 2 C1.

Warning:
In this case the spacing is comparable to the system size, so the plate capacitor formula cannot be legitimate (i.e., the fringe or edge field effect is too large and C = ¥epsilon A/d is wrong.

23. A charged particle ($q = 0.5$ μC) moves in a uniform electric field ($E = 1.2\times10^7$ N/C, in the +x direction) from **A** to **B** as shown. The starting point, **A**, is at (x=0.15 m, y=0.14 m), and the ending point, **B**, is at (x=0.215 m, y=0.14 m). How much work does the electric field do on the particle as it moves from **A** to **B**?

a. -1.2 J

Compare the initial and the final potential energy.

b.   0 J

c. +1.2 J

The motion is along equipotential line, so no potential changes. NO WORK.
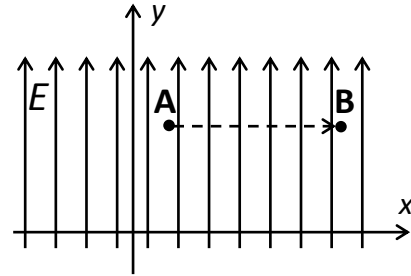
24. A collection of large capacitors connected in parallel is used in operating an accelerator in a radiation oncology practice. The total capacitance is C = 1F. Assuming the capacitors are operated with a voltage of V=110 V, how much energy can be stored?

a. 55 J

$U = (1/2)\ CV^2 = (1/2)Q^2/C$

b. 305 J

c. 610 J

$U = (1/2)\ 110^2 = 6050$ J.

d. 6050 J

e. 12100 J

25. A naval rail gun has accelerated a projectile to 3km/s. The projectile has a kinetic energy of 490kJ. The energy for rail gun shots is stored in large capacitors. If the capacitance used is C_R=2F, how much charge was stored in the capacitor just before the shot was fired?

a.   70 C

We must store 490 kJ in the capacitor:

$U = (1/2)\ Q^2/C$

b. 490 C

c. 700 C

so

d. 1400 C

$Q^2 = 2UC = 2 \times 490\times10^3 \times 2 = 1960 \times 10^3$

e. 2800 C

$= 1400^2$

this should be ¥kappa

26. Two large parallel aluminum plates are isolated and separated by an adjustable distance. A container of water (with dielectric constant ε=80) has been placed between the plates. Which change to the setup would increase the capacitance of the plates?

C = ¥epsilon0¥kappa A/d

a. Increasing the distance between the two plates. ✗
b. Removing the container of water. ✗ This decreases ¥kappa to 1.
c. Adding a second container of water between the plates while keeping the distance between them fixed.   This increases (effective) ¥kappa.

27. A metal box carries a charge $Q_M = +1C$. An insulating, polarizable ball that carries no net electric charge, $Q_1 = 0C$, is held in place with a rod so that it is located near the box. Which statement with regards to the force between the rubber ball and the metal box is correct?

a. There will be no force since $Q_1 = 0C$.
b. There will a repulsive force.
c. There will be an attractive force.

$Q_1 = 0C$

$Q_M = +1C$
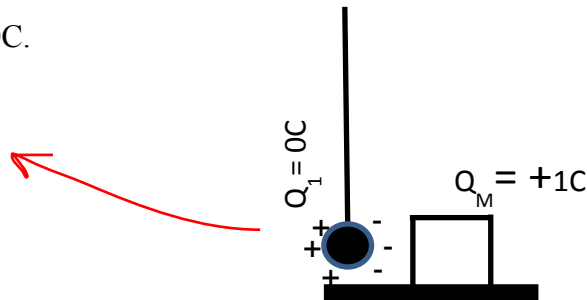
**Check to make sure you bubbled in all your answers.
Did you bubble in your name, exam version and network-ID?**