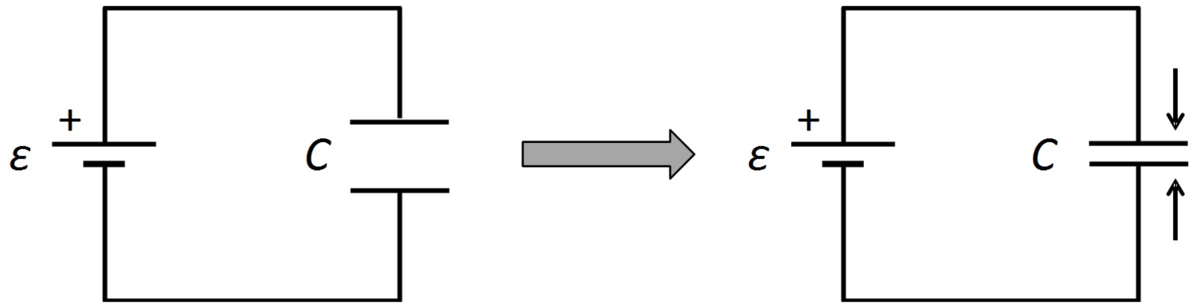
1) A parallel plate capacitor is connected to a 9 V battery, as shown below. At some time, the parallel plates are moved a small distance *closer* together.



What happens to the charge $Q \geq 0$ stored on the top capacitor plate? Note that the capacitor remains connected to the battery throughout.

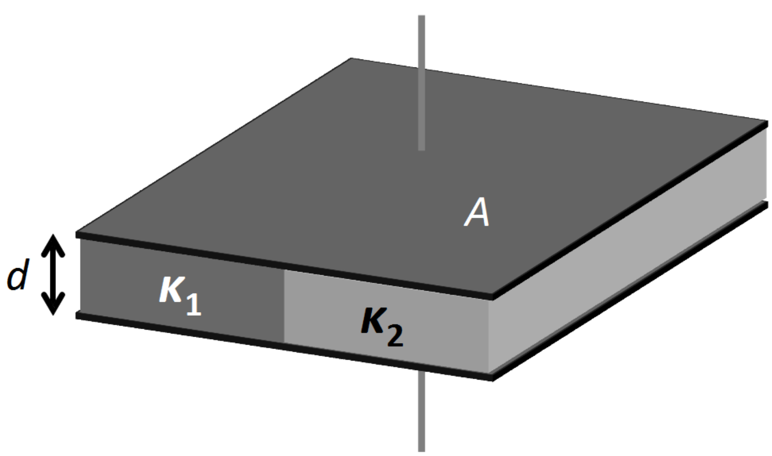
C = ¥kappa ¥e_0 A/d

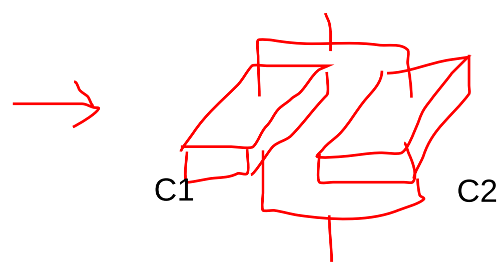
Stored charge
Q = CV

✓ a. Q increases
b. Q remains the same
c. Q decreases

Since V is constant, Q is proportional to 1/d. Decreasing d increases Q.

2) The capacitor below is made of two parallel plates of area $A = 20\ cm^2$ separated by a distance $d = 3\ mm$. As shown below, two slabs of dielectric with dielectric constants $\kappa_1 = 2$ and $\kappa_2 = 4.5$ are placed between the two plates and take up *exactly half* the volume between the plates.





= C1 + C2

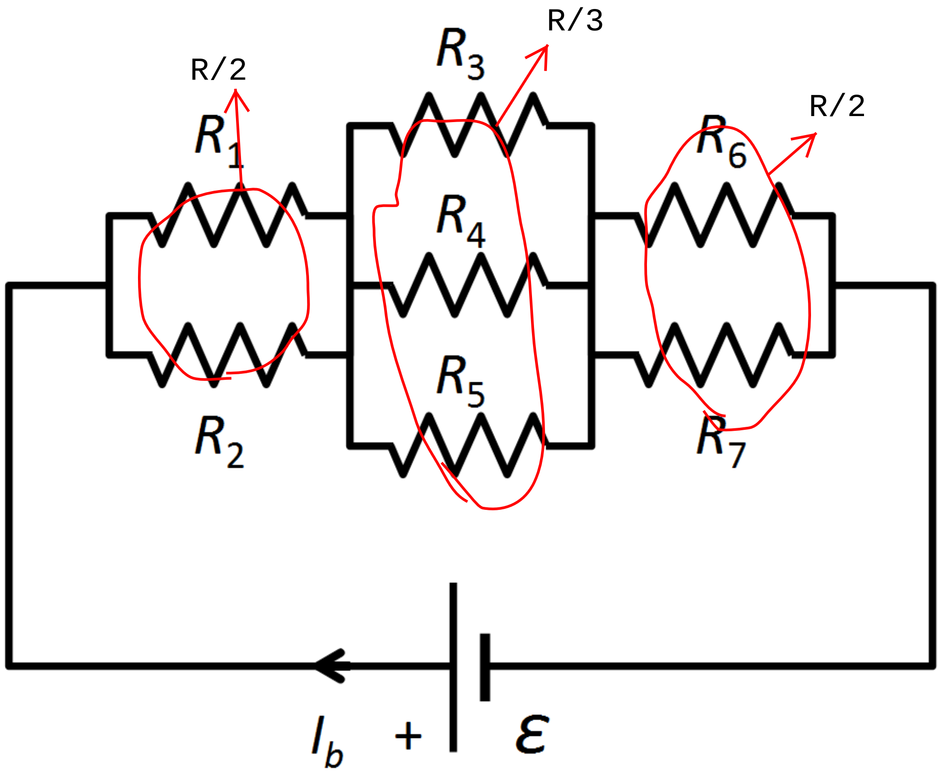
Calculate the capacitance *C* of this capacitor.

a. $C = 50\ pF$
✓ b. $C = 19\ pF$
c. $C = 67\ pF$
d. $C = 81\ pF$
e. $C = 11\ pF$

You can interpret this as parallelly connected two capacitors with area A/2. C1 = K1e_0 A/2d, C2 = K2e_0A/2d, so
C = [(K1+K2)/2]¥e_0 A/d
= 3.25 x 8.85 x 10^{-12} x (20 x 10^{-4})/(3 x 10^{-3})
= 191.75 x 10^{-12-4+3} = 1.92 x 10^{-11} = 19.2 pF

The next two questions pertain to the situation described below.

Consider the following network of resistors. All of the resistors have the same resistance R. The network is connected to a battery with emf ε, through which a current I_b passes.



in series
R = R1 + R2
in parallel
R = R1R2/(R1 + R2)

3) Calculate the equivalent resistance R_{eq} of the network.

Req = R/2 + R/3 + R/2 = 4R/3.

a. $R_{eq} = R/3$
b. $R_{eq} = R/2$
✓ c. $R_{eq} = 4R/3$
d. $R_{eq} = R$
e. $R_{eq} = 3R/8$

4) Calculate the current I_4 through resistor R_4 in terms of the battery current I_b.

current must be conserved.

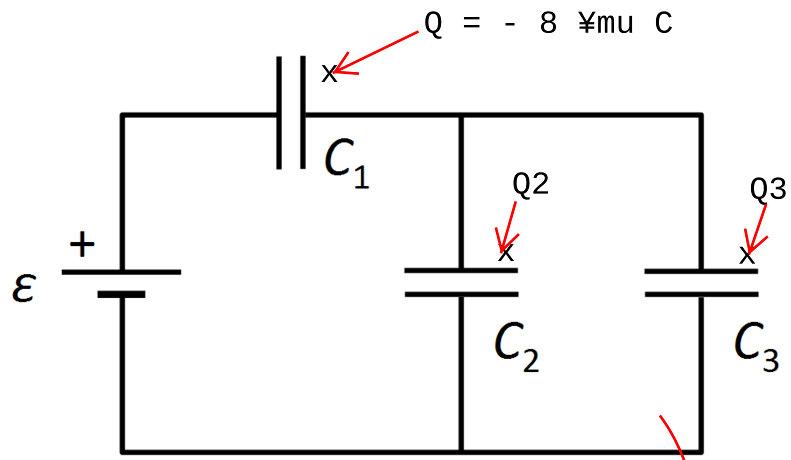
✓ a. $I_4 = I_b / 3$
b. $I_4 = 3I_b / 8$
c. $I_4 = 4I_b / 3$
d. $I_4 = I_b / 2$
e. $I_4 = I_b$

by symmetry you can at once conclude I4 = Ib/3

If you wish to go reallhy step by sep:
I3 = I4 = I5
I3 + I4 + I5 = Ib
Hence, 3I_4 = Ib -> I4 = Ib/3.

The next three questions pertain to the situation described below.

The following circuit contains three capacitors $C_1 = 19\ \mu F$, $C_2 = 1\ \mu F$, and $C_3 = 7\ \mu F$ connected to a battery with an unknown emf ε. The charge on capacitor C_1 is $Q_1 = 8\ \mu C$.



5) How much energy is stored on capacitor C_1?

E = Q^2/2C

✓ (a.) $E = 1.7 \times 10^{-6}\ J$
b. $E = 5.9 \times 10^{-6}\ J$
c. $E = 2.9 \times 10^{-6}\ J$
d. $E = 4.7 \times 10^{-7}\ J$
e. $E = 9.4 \times 10^{-7}\ J$

```
We know C1 = 19 ¥mu F, Q1 = 8 ¥mu C, so
E = 8^2/(2 x 19) = 1.68 ¥mu J.
```

6) What is the charge Q_2 on capacitor C_2?

Charge conservation

a. $Q_2 = 2.6\ \mu C$
b. $Q_2 = 0.56\ \mu C$
✓ (c.) $Q_2 = 1\ \mu C$
d. $Q_2 = 3.5\ \mu C$
e. $Q_2 = 1.7\ \mu C$

```
Charge conservation tells us that
     Q + Q2 + Q3 = 0 -> Q2 + Q3 = 8 ¥muC
The voltages across C2 and C3 must be identical:
     Q2/C2 = Q3/C3 or Q2 = Q3/7.
Therefore, Q1 = 1 and Q3 = 7.
```

7) What is the equivalent capacitance C_{eq} of the circuit?

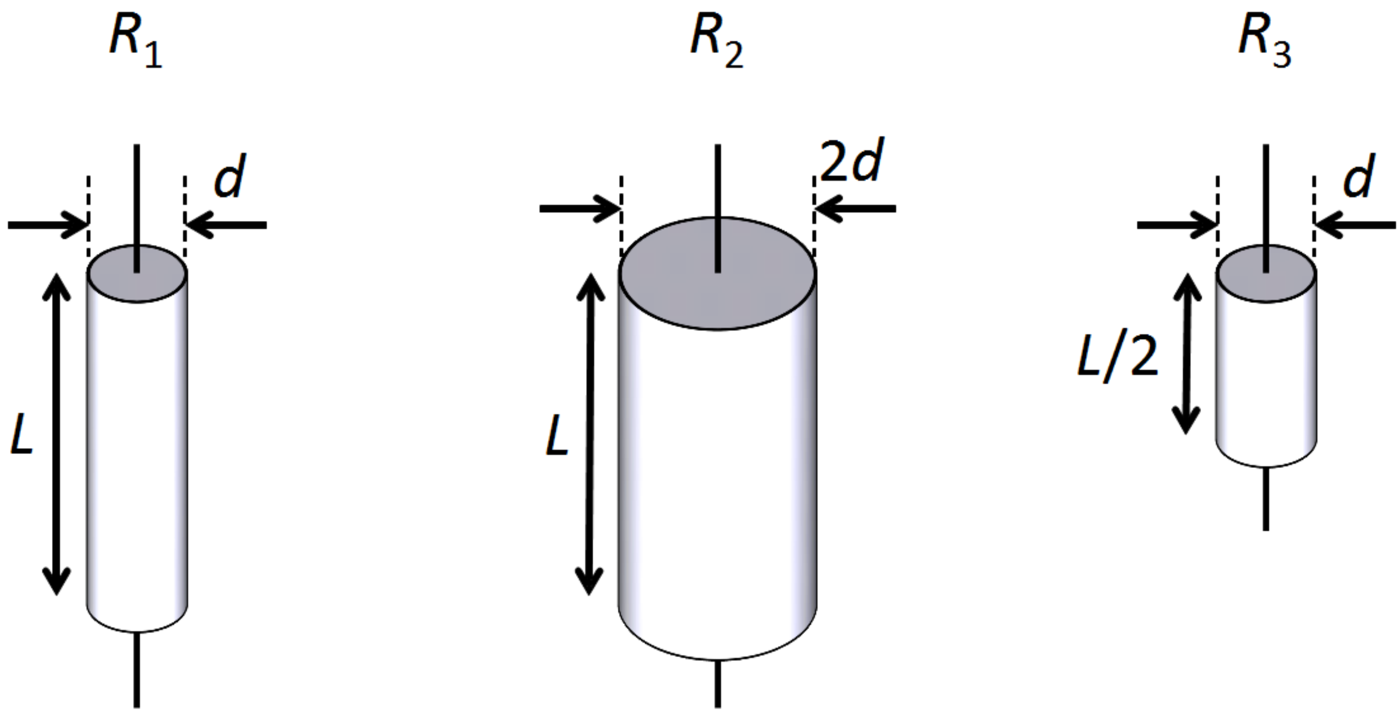
in series
  C = C1C2/(C1 + C2)
in parallel
  C = C1 + C2

✓ (a.) $C_{eq} = 5.6\ \mu F$
b. $C_{eq} = 9.6\ \mu F$
c. $C_{eq} = 3\ \mu F$
d. $C_{eq} = 15\ \mu F$
e. $C_{eq} = 20\ \mu F$

```
Ceff = C1(C2 + C3)/(C1 + C2 + C3)
     = 19x8/27 = 5.62 ¥mu F.
```

The next two questions pertain to the situation described below.

Consider the three resistors below made of identical material but of different dimensions.



R = ¥rho L/A

P = I^2 R = V^2/R

```
R1 = ¥rho L/(¥pi d^2)
R2 = ¥rho (L)/(¥pi (2d)^2) = R1/4
R3 = ¥rho (L/2)/(¥pi d^2) = R1/2
so
R2 < R3 < R1
```

8) If the same current *I* passes through each resistor, which resistor dissipates the *most* power?

```
Use P = I^2R, so larger R gives larger P.
```

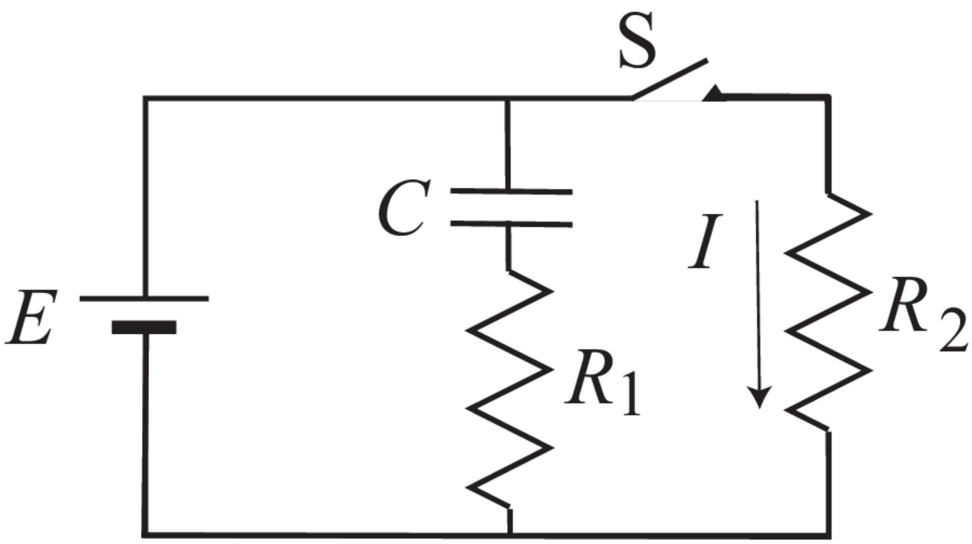
✓ a. R_1
b. R_2
c. R_3

9) If the same voltage *V* is applied across each resistor, which resistor dissipates the *most* power?

```
Use P = V^2/R, so smaller R gives larger P.
```

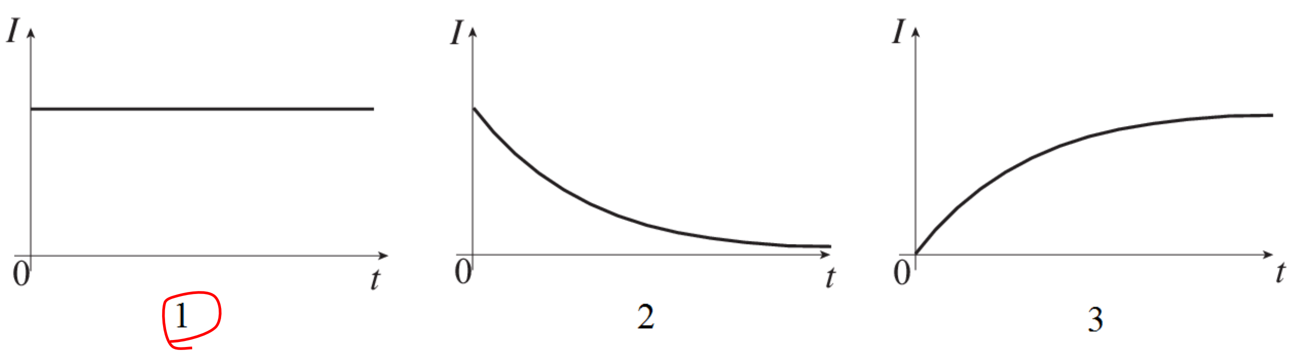
a. R_1
✓ b. R_2
c. R_3

10) In the following RC circuit with a switch S, two resistors R_1 and R_2 have the same resistance $R = 20\ \Omega$, C denotes a capacitor of capacitance $15\ \mu F$, and E denotes a 12 V battery.



Initially, switch S is open for a long time. After $t = 0$ switch S is closed. Choose the best figure from below describing the time-dependence of the current I through R_2. Do not forget that the battery E is still connected.

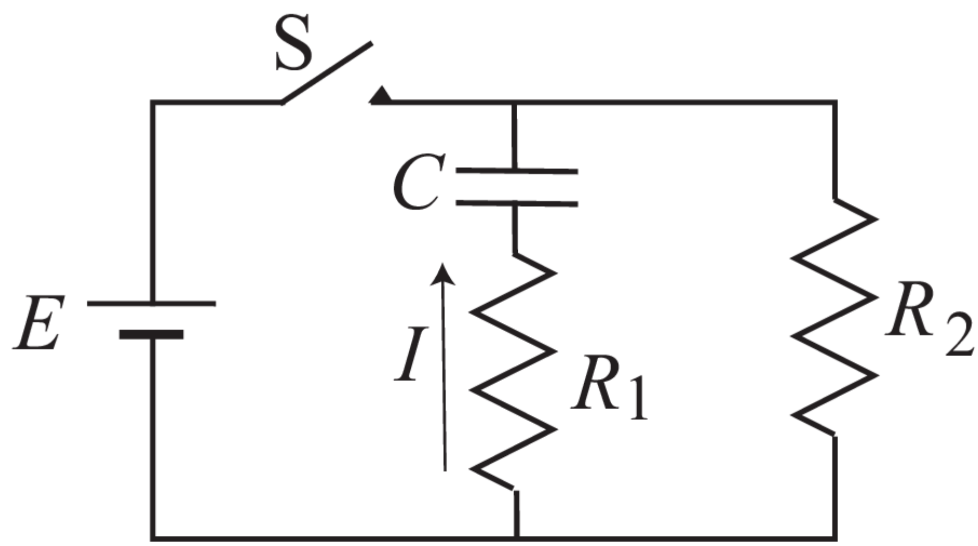
The voltage across R2 is always E, so I = E/R2 = constant.



a. 3
b. 2
✓ c. 1

The next two questions pertain to the situation described below.

In the following RC circuit with a switch S, two resistors R_1 and R_2 have the same resistance $R = 29\ \Omega$, C denotes a capacitor of capacitance $7\ \mu F$, and E denotes a 12 V battery.



11) Switch S has been closed for a long time. What is the current I through R_1 immediately after S is opened? Pay attention to the direction of the current arrow in the figure.

a. $I = +0.41\ A$
b. $I = -0.21\ A$
✓ c. $I = +0.21\ A$
d. $I = 0\ A$
e. $I = -0.41\ A$

```
When S is closed for a long time, I = 0, so the voltage
across C is E.
Immediately after S is opened, the voltage across C cannot
change immediately, so C behaves just as a battery of 12 V.
The current goes through R1 and R2 in series, so
     I = 12/(29+29) = 0.2069 A clockwise.
```

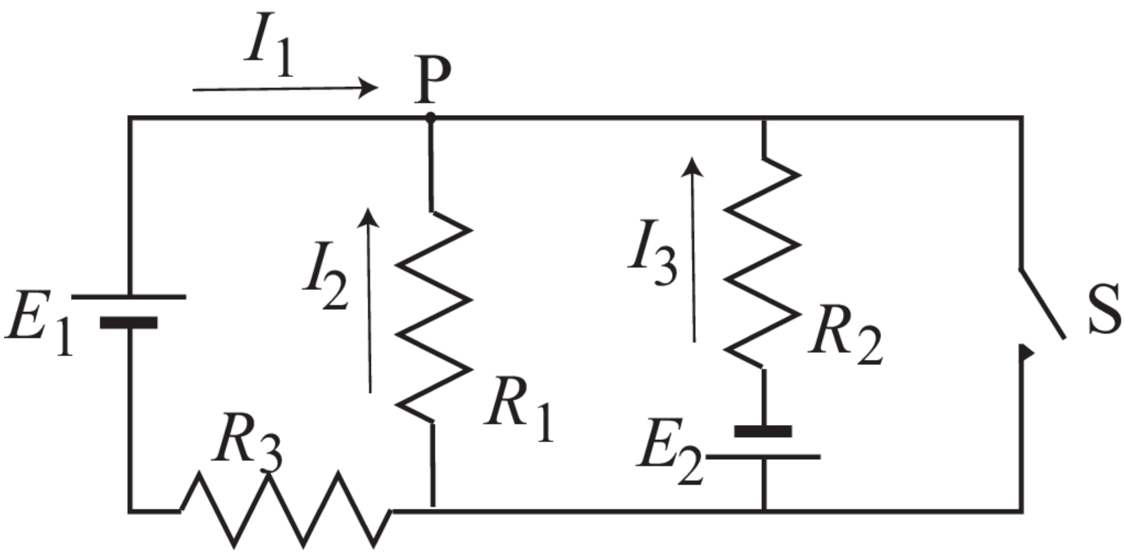
12) What is the voltage V_2 across resistor R_2 at a time of 0.5 ms after switch S is opened?

a. $V_2 = 3.2\ V$
b. $V_2 = 0.51\ V$
✓ c. $V_2 = 1.8\ V$

```
The current decays exponentially: I = I_0 exp(-t/¥tau),
so the voltage across R2 must aslo behave as
     V = V_0  exp(-t/¥tau),
where ¥tau = C(R1+R2) = 7 x 58 = 406 ¥mu s = 0.406 ms.
V_0 = 6 V, obviously:
     V = 6 exp(-0.5/0.406) = 1.75 V.
```

The next two questions pertain to the situation described below.

In the following figure, $E_1 = 12\ V$, $E_2 = 4\ V$, $R_1 = 7\ \Omega$, $R_2 = 12\ \Omega$, and $R_3 = 4\ \Omega$. Initially, the switch S is open.



Kirchhoff's junction rule.
Total current input = total current output

13) At junction P three currents I_1, I_2, and I_3 meet. Choose the correct relation among them from below.

✓ a. $I_1 + I_2 + I_3 = 0$
b. $I_1 - I_2 - I_3 = 0$
c. $-I_1 + I_2 - I_3 = 0$
d. $I_1 - I_2 + I_3 = 0$
e. $I_1 + I_2 - I_3 = 0$

I1, I2 and I3 are coming in, and nothing is going out, so
I1 + I2 + I3 = 0.

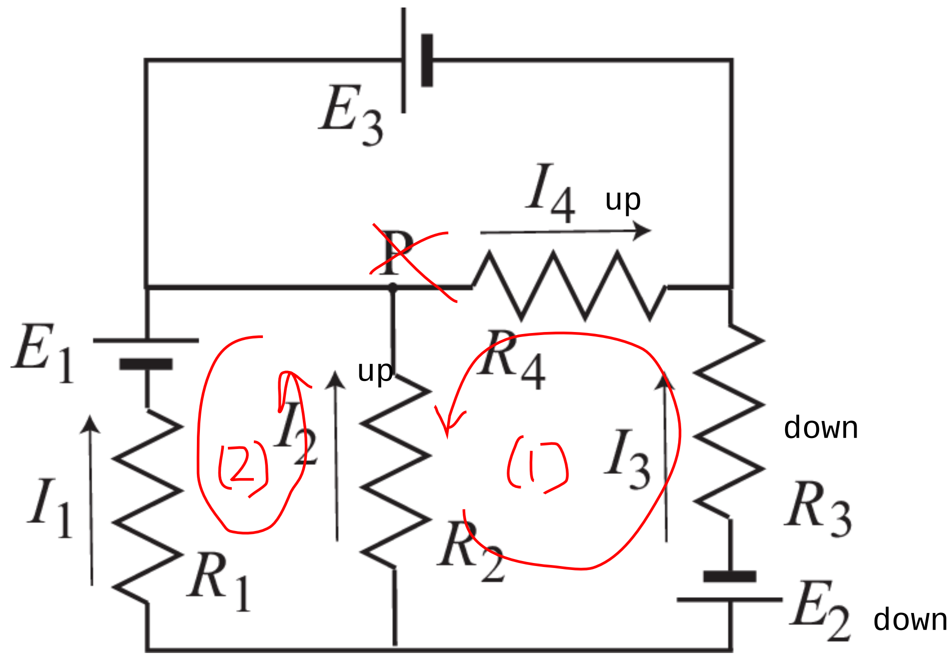
14) When the switch S is closed, what is the current I_3?

a. $I_3 = 0\ A$
b. $I_3 = -0.57\ A$
c. $I_3 = -0.75\ A$
✓ d. $I_3 = -0.33\ A$
e. $I_3 = -0.7\ A$

The voltage across R2 is E2, so I3 = E2/R3 or 4/12 = 1/3 A, counterclockwise.

The next three questions pertain to the situation described below.

In the following figure, $E_1 = 12\ V$, $E_3 = 7\ V$, $R_1 = R_2 = R_3 = R_4 = 3\ \Omega$. E_2 is not known.



Kirchhoff's loop law

15) Choose the correct formula exhibiting Kirchhoff's loop law from the following formulas.

✓ a. $I_2R_2 + I_4R_4 - I_3R_3 - E_2 = 0$
b. $I_2R_2 - I_4R_4 - I_3R_3 + E_2 = 0$
c. $I_2R_2 + I_4R_4 - I_3R_3 + E_2 = 0$
d. $I_2R_2 + I_4R_4 + I_3R_3 - E_2 = 0$
e. $I_2R_2 + I_4R_4 + I_3R_3 + E_2 = 0$

```
Consider the loop (1) in the figure.
down -> 1 up -> +, so
I2R2 -E2 -I3R3 + I4R4 = 0.
```

16) What is the current I_4? Pay attention to the direction of the current arrow in the figure.

```
The voltage across R4 is just E3:
    I4 = 7/3 = 2.333 A counterclockwise.
```

a. $I_4 = 0\ A$
b. $I_4 = +1.2\ A$
c. $I_4 = -2.3\ A$
✓ d. $I_4 = +2.3\ A$
e. $I_4 = -1.2\ A$

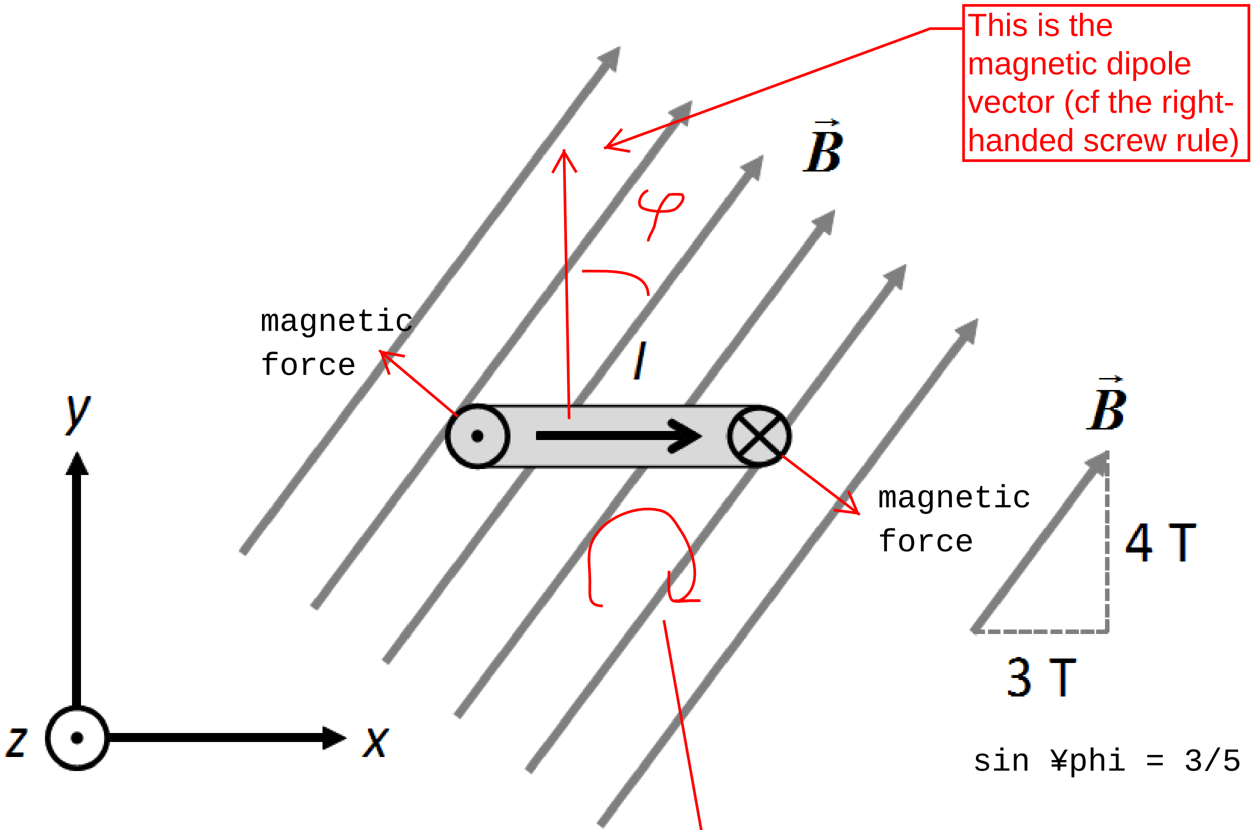
17) The current I_2 is measured to be $-1.5\ A$. What is the current I_1? Again, pay attention to the direction of the current arrow in the figure.

✓ a. $I_1 = +2.5\ A$
b. $I_1 = -2.5\ A$
c. $I_1 = -5.5\ A$
d. $I_1 = +5.5\ A$
e. $I_1 = 0\ A$

```
Around loop (2) Kirchhoff tells us that
     -E1 + I1R1 - I2R2 = 0
so
     3I1 - 12 + 3x1.5 = 0 or 3 I1 = 12- 4.5 = 7.5,
that is, I1 = 2.5 A.
```

The next two questions pertain to the situation described below.

A current carrying loop of radius $r = 14\ cm$ is oriented horizontally, with its area parallel to the x~~y~~z-plane in the figure below, and a uniform magnetic field is applied that has no z-component. The x-component of the B field is $3\ T$ and its y-component is $4\ T$. The current $I = 7\ A$ is flowing into the (–z) direction at the rightmost point of the loop, as denoted in the figure that shows a side view of the loop. (The (–z)-direction points into the page).



18) What is the **magnitude** of the torque on the current loop?

torque = ¥mu B sin ¥phi

¥mu = NIA (N = 1 here)

a. $\tau = 1.7\ N{\cdot}m$
b. $\tau = 2500\ N{\cdot}m$
c. $\tau = 2.2\ N{\cdot}m$
✓ d. $\tau = 1.3\ N{\cdot}m$
e. $\tau = 1800\ N{\cdot}m$

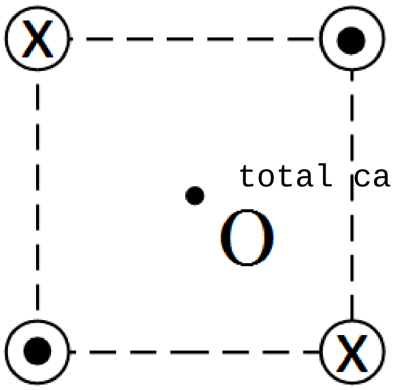
torque = 7x(¥pi x 0.14^2)x 5 x(3/5)
= 1.293 N.m

19) In which direction will the loop *start to turn* if left free?

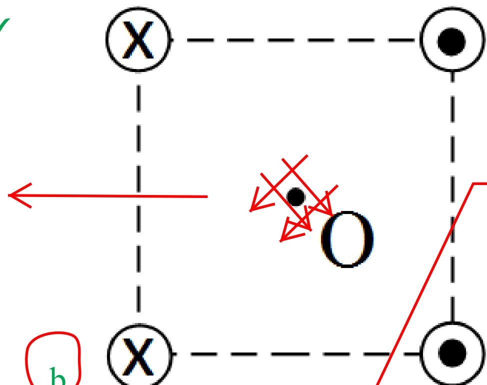
✓ a. Clockwise about an axis parallel to the z-axis
b. Counter-clockwise about an axis parallel to the z-axis
c. Around an axis that is *not* parallel to the z axis.

20) Four long straight wires carrying currents of equal magnitude ($I_1 = I_2 = I_3 = I_4 = I$) are parallel or antiparallel to each other such that their cross sections form the corners of a square, as shown in the figures. The figures indicate the directions of the current in each wire. In which case is the magnitude of the total magnetic field at the center of the square (O) the largest?

right-handed screw rule
B = ¥mu_0I/2¥pi r



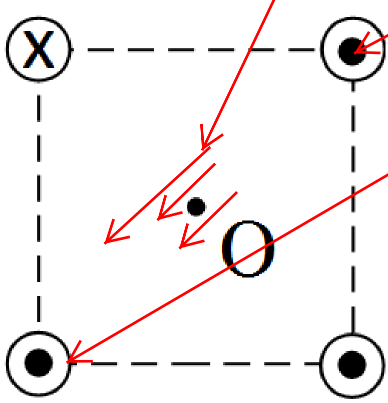
a.



This is the total field.

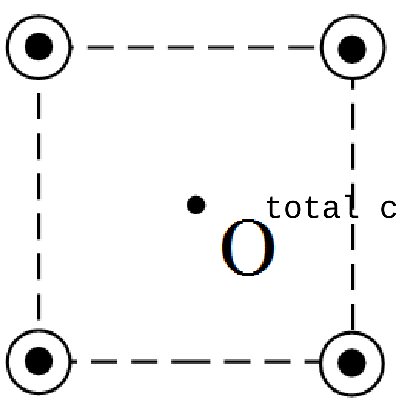
Their contributions cancel each other.

b.



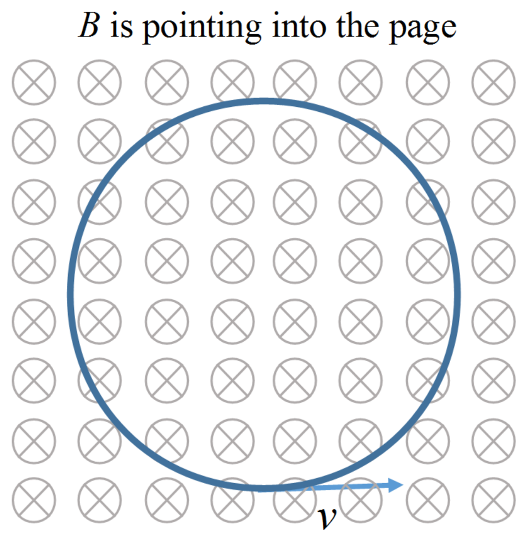
b is ¥sqrt{2} times this.

c.



d.

21) A charged particle travels counterclockwise with speed *v* on a circle in the plane of the page, while a uniform magnetic field *B* is applied in a perpendicular direction, pointing into the page (as shown below). The period *T* is the amount of time the particle takes to travel around one complete circle. How would the period change if the speed of the particle was doubled?

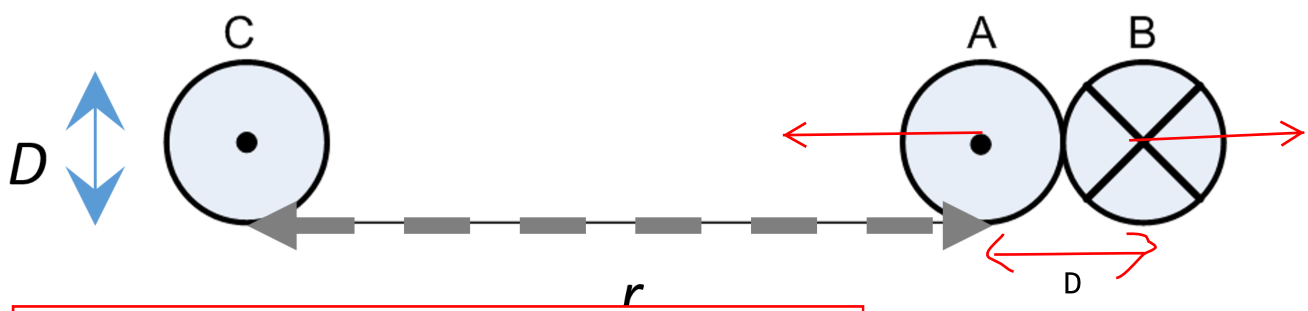


mv^2/r = qvB or
r = mv/qB

```
T = 2¥pi r/v = 2¥pi m/qB
Thus v is irrelevant.
```

a. *T* would increase by a factor of 4.
✓ b. *T* would remain unchanged.
c. *T* would increase by a factor of 2.
d. *T* would decrease by a factor of 2.
e. *T* would decrease by a factor of 4.

22) Three long, parallel straight wires A, B and C carry a constant current of $I = 3\ A$ each. The direction of the current of each wire is as indicated in the figure below. The length of the wires is $L = 1\ m$ and the diameter is $D = 8\ mm$. Wires A and B are stuck to each other but electrically insulated from each other. We call the combination of wires A and B a "double wire AB". The distance from the center of C to the center of A is $r = 2\ cm$.



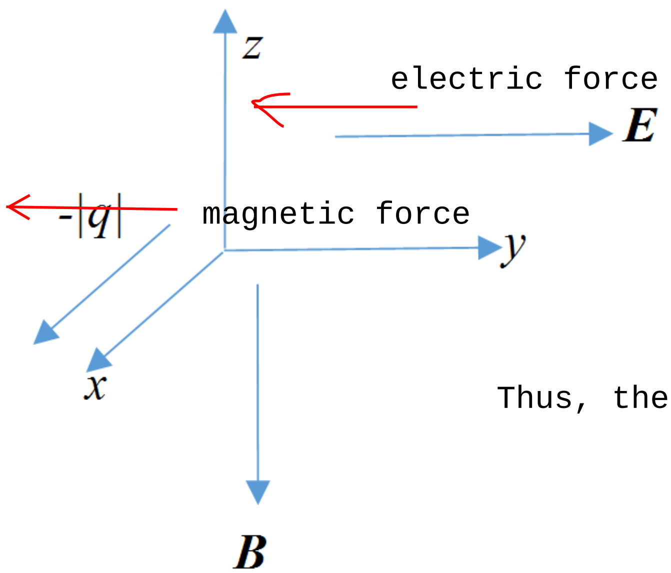
B = ¥mu_0 I/2¥pi r
The force is F = ILB, since I and B are orthogonal.

What is the net force on the double wire AB due to wire C?

a. $F = 1.5 \times 10^{-4}\ N$
b. $F = 0\ N$
✓ c. $F = 2.6 \times 10^{-5}\ N$

```
F(AC) = (¥mu_0/2¥pi)I^2/r, (per unit length)
F(BC) = (¥mu_0/2¥pi)I^2/(r+D)
The directions are opposite.
Total force = (¥mu_0/2¥pi)I^2(1/r - 1/(r+D))
      = 2 x 10^{-7} x 3^2 (1/0.02 - 1/0.028)
      = 257.1 x 10^{-7} = 2.57 x 10^{-5} N
```

23) A particle of charge $-|q|$ moves in the positive x-direction with speed v. There is a uniform electric field $\boldsymbol{E}$ of magnitude $|E|$ pointing in the positive y-direction and a uniform magnetic field $\boldsymbol{B}$ pointing in the *negative z-direction*. What must be the magnitude of the magnetic field, $|E|$, such that the particle does not accelerate? (Hint: Pay careful attention to the given direction of $\boldsymbol{E}$ and $\boldsymbol{B}$).



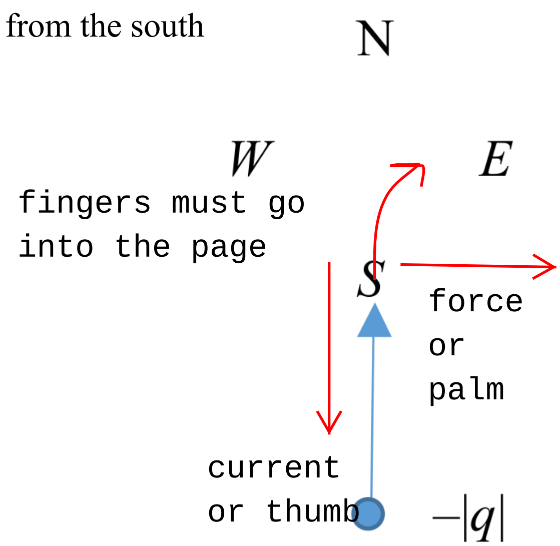
Thus, there is no possibility of force balance.

a. $|B| = |E|$
✓ b. The charge will accelerate for any magnetic field $\boldsymbol{B}$ pointing in the negative z-direction.
c. $|B| = |E|/v$

24) A negatively charged particle enters a uniform magnetic field from the south and is pushed to the east.

In which direction does the magnetic field point?

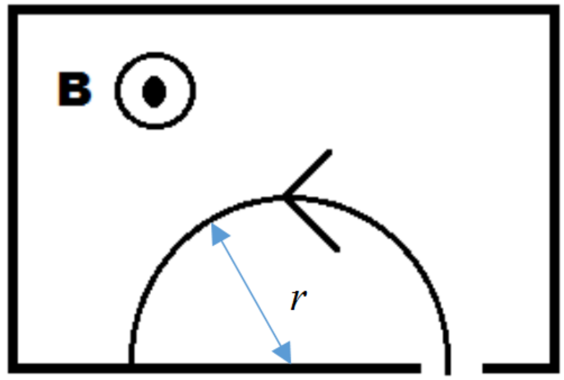
Right-hand rule



✓ a. The magnetic field points into the page.
b. The magnetic field points out of the page.

The next two questions pertain to the situation described below.

A negatively charged particle with charge $q = -3e$ enters a uniform magnetic field $B = 0.3\ T$ pointing out of the page with a speed of $v = 10^6\ m/s$ and sweeps out a half circle of radius $r = 5.9\ cm$ before leaving the field.



25) What is the particle's mass? r = mv/qB

a. More information is required to determine the mass of the particle.
b. $m = 2.8 \times 10^{-20}\ kg$
✓ c. $m = 8.5 \times 10^{-27}\ kg$
d. $m = 8.5 \times 10^{-21}\ kg$
e. $m = 2.8 \times 10^{-26}\ kg$

```
m = qBr/v
  = 3x1.6x10^{-19} x 0.3 x 0.059/10^6
  = 0.08496 x 10^{-25} = 8.5 x 10^{-25-2} kg
```

26) What is the speed v of the particle upon exiting the region with the B field?

v and B are orthogonal, so B cannot do any work.

a. $v = 10^5\ m/s$
b. $v = 10^7\ m/s$
c. $v = 10^4\ m/s$
d. $v = 0\ m/s$
✓ e. $v = 10^6\ m/s$

The kinetic energy must be conserved, so there is no change in speed.