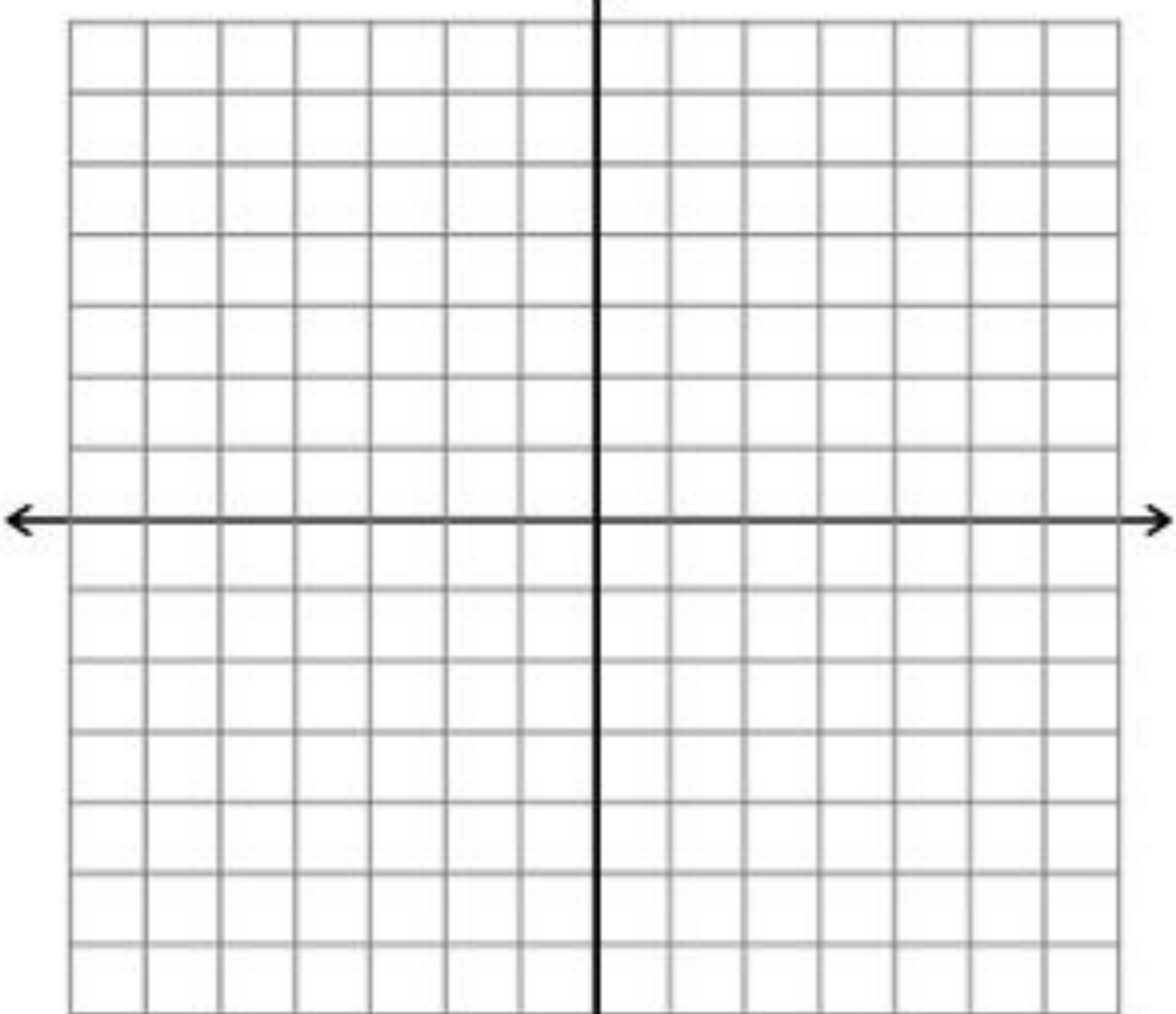


Electric Field: analogous to gravitational field: $F=m_1(Gm_E/r_E^2)$;

$(Gm_E/r_E^2)=g$ $=9.8\ m/s^2$ at surface of earth: "Grav. *field* or grav. *acceleration*"

Important point: **g** depends only on earth properties (m_E and r_E); same for all m_1 vals.

Similarly, $F_{Electric}=kq_1q_2/r^2=q_1(kq_2/r^2)$;

Electric field E for charge $2=(kq_2/r^2)$, or can rewrite: $F_{Electric}=kq_2q_1/r^2=q_2(kq_1/r^2)$; now $E_1=(kq_1/r^2)$

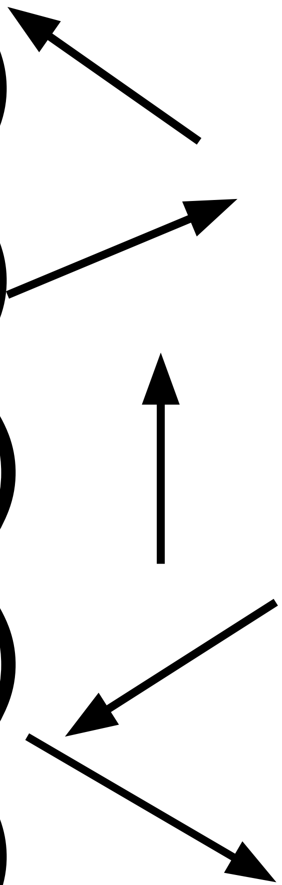
<u>E fields point away from/towards +/- sources!</u>

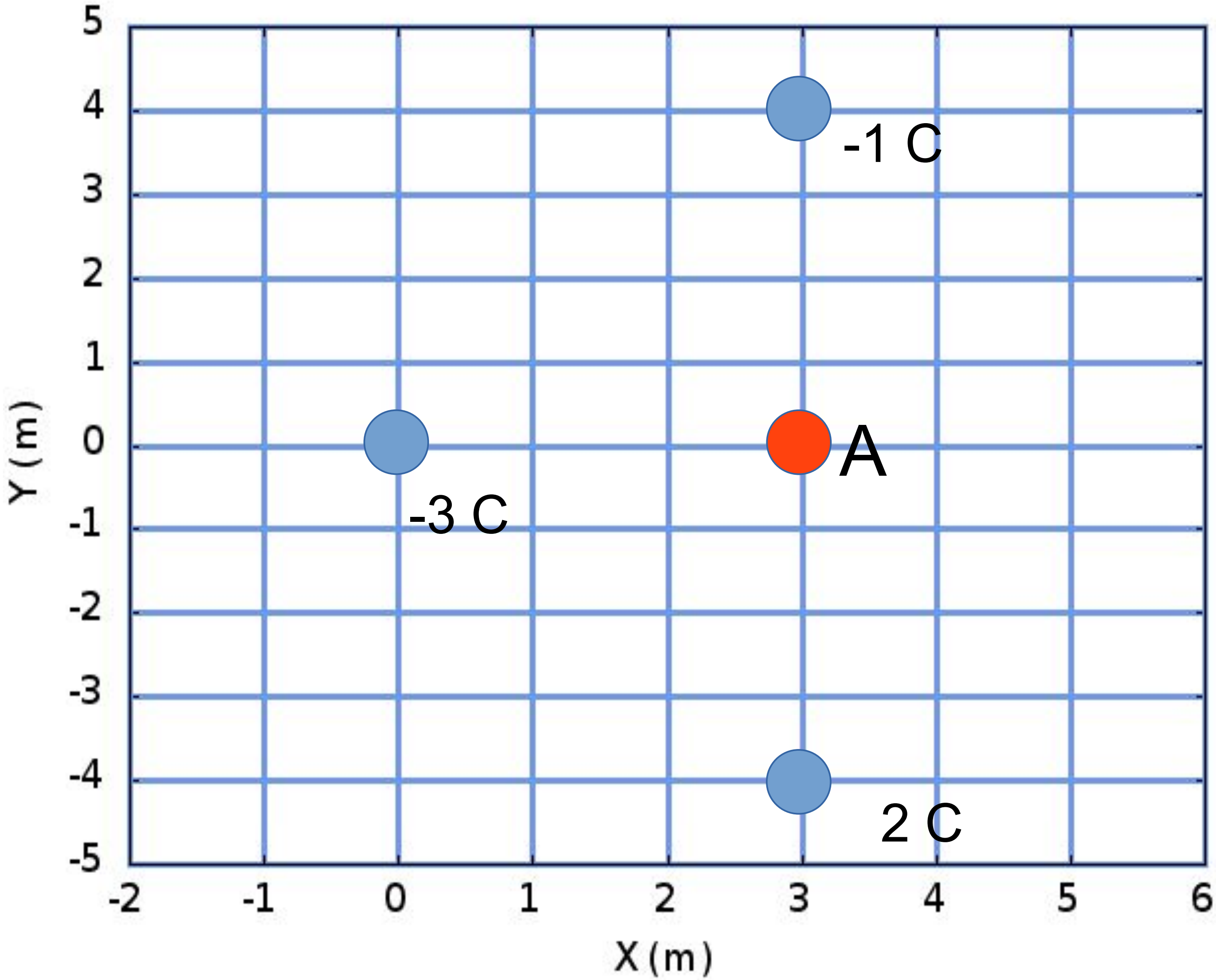
“The Moral Arc of History is Long, But Surely it Bends Towards Justice”

A) agree
B) disagree
C) who cares?

The direction of E_{net} at pt. A is closest to:

A)
B)
C)
D)
E)





In the previous problem, $|E_{net}|$ at the point (A)=

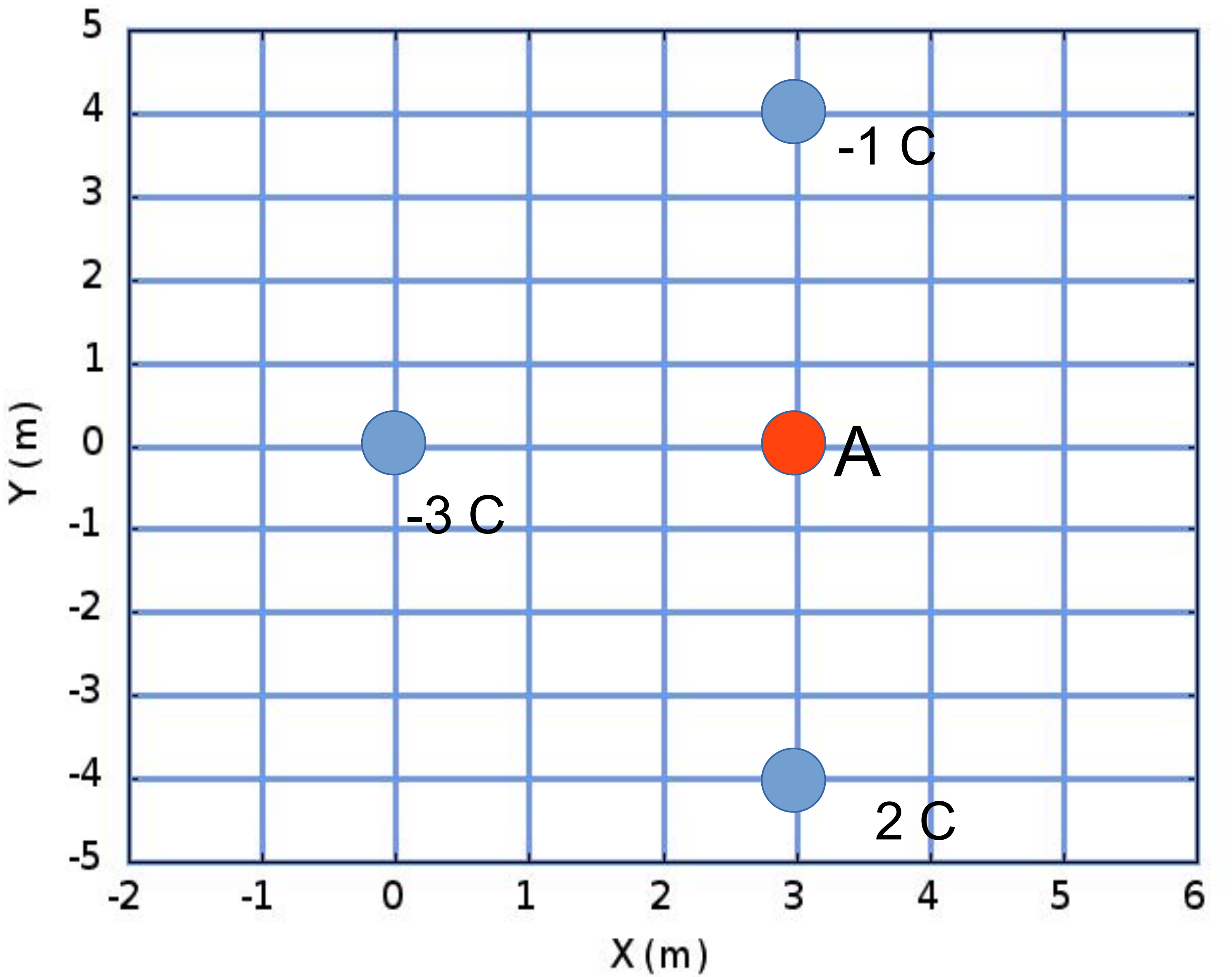
A) 0.162 k N/C

B) 0.324 k N/C

C) 0.648 k N/C

D) 0.382 k N/C

E) NOTA



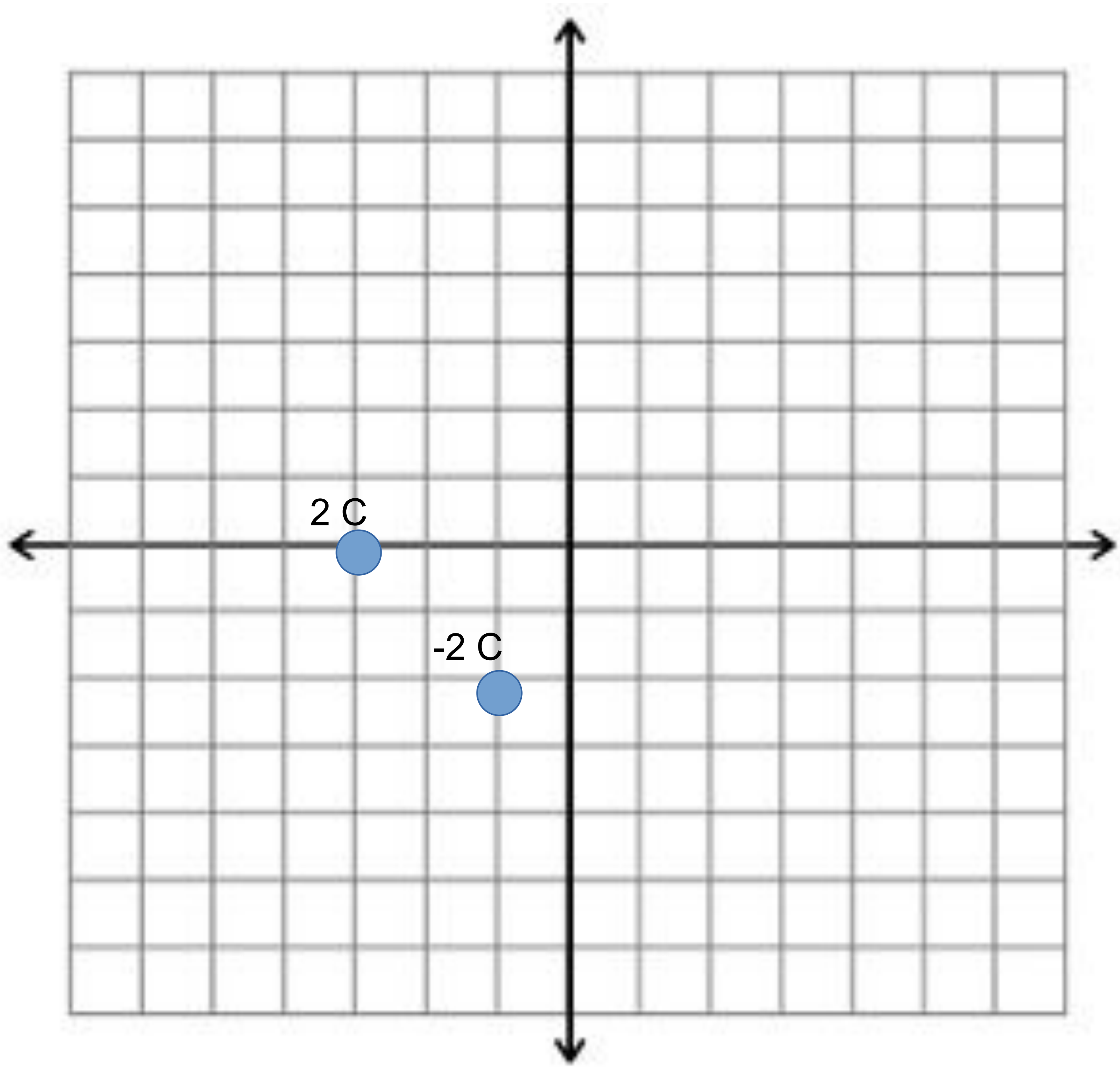
The E-field direction at (0,0) is (for CAP1, you'll need to check your graphical answer numerically!):

A) NE

B) NW

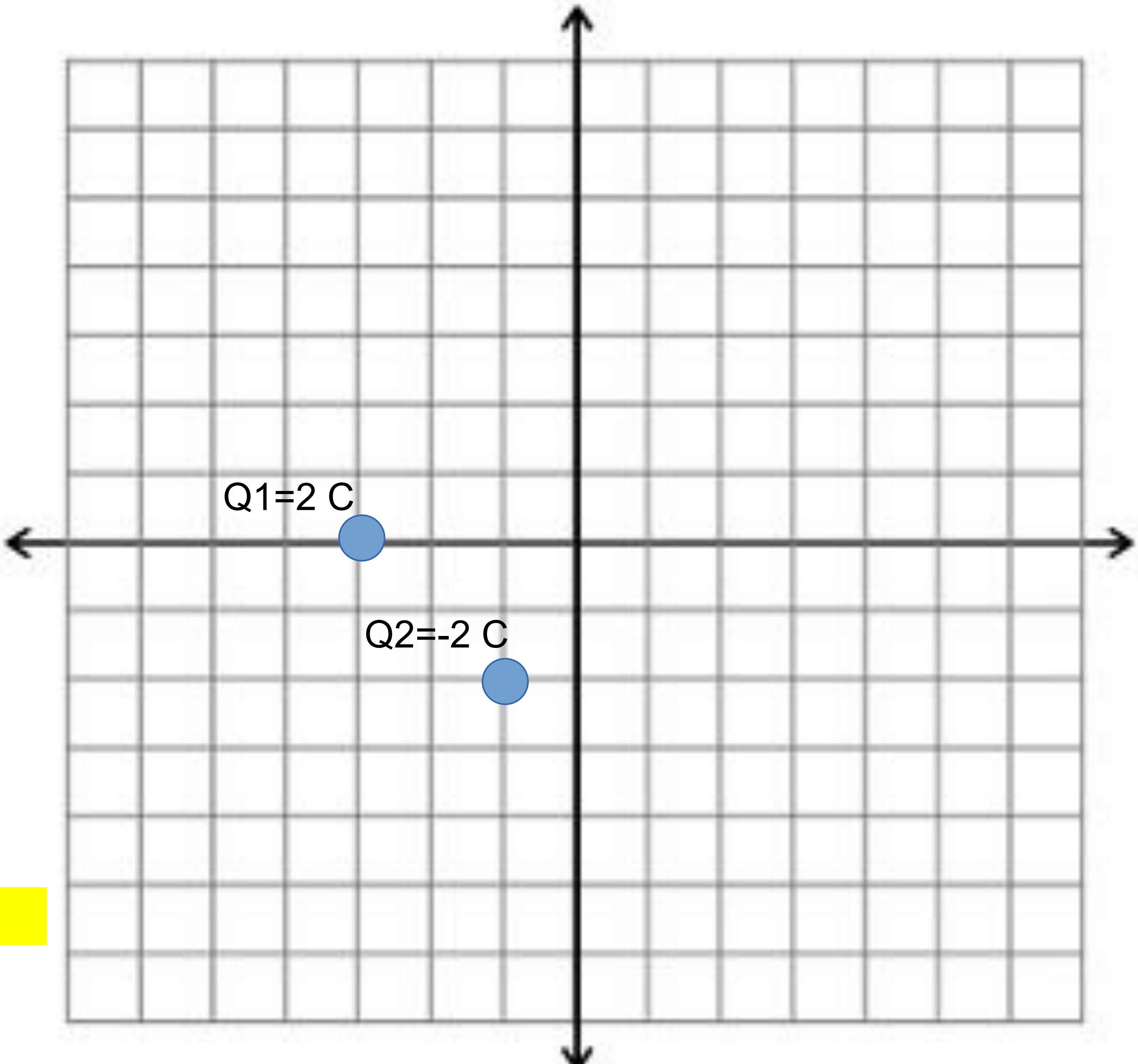
C) SE

D) SW



A -0.1 C charge q is now placed at the origin, and released. Given that the force on q is given by F=qE, what is q's acceleration direction?

A) NE
B) NW
C) SE
D) SW



What if q was +0.1C?

The direction of E_{net} at point A is closest to:

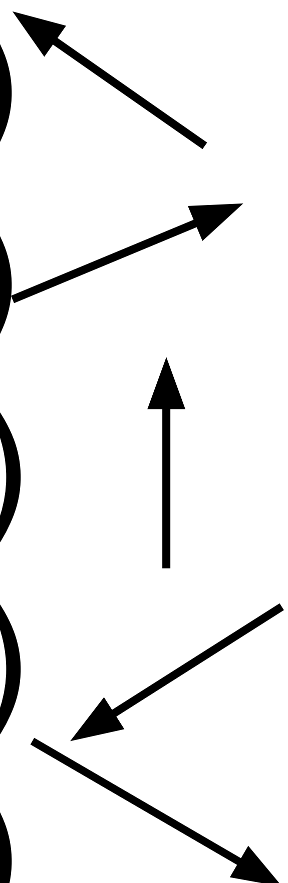
A)

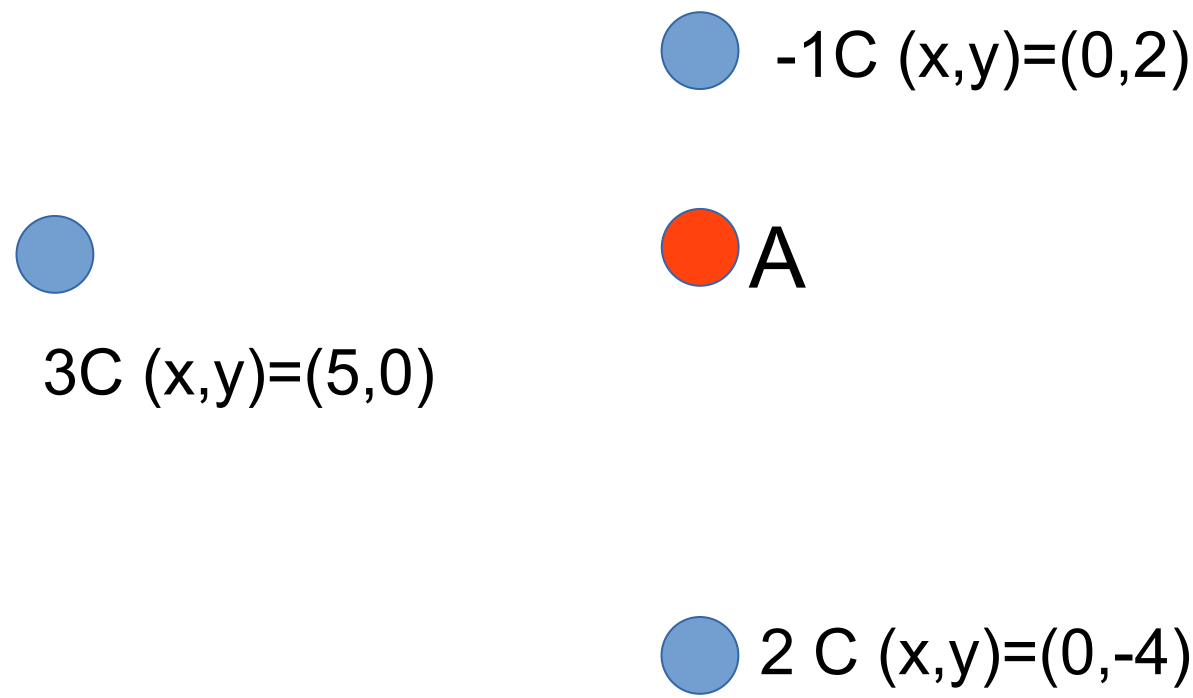
B)

C)

D)

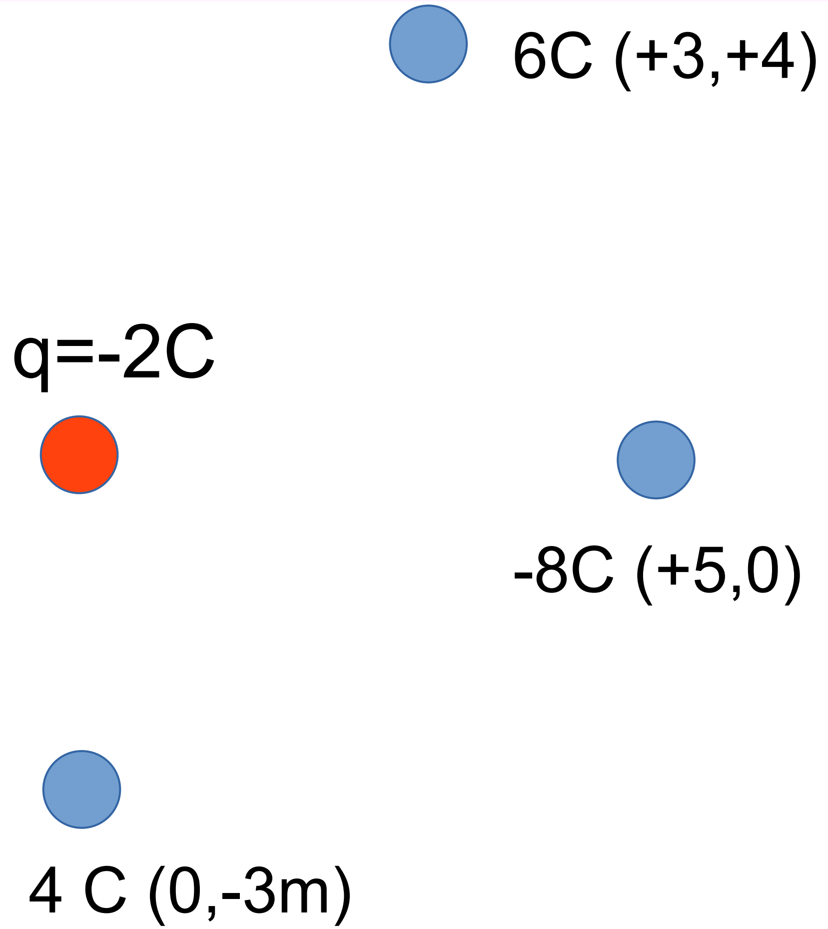
E)





What is the force direction on the q=-2C charge at (0,0)?

A) NW
B) NE
C) SW
D) SE
E) NOTA



In the previous problem, the net x-component of *force* on the -2C charge is:

A) 1.77k N

B) 0.384k N

C) -0.352k N

D) -0.712k N

E) NOTA

In the same problem, F_y=

A) 0.621k N

B) -1.27k N

C) 1.27k N

D) -0.505k N

E) NOTA

A -1C charge and a +2C charge are placed 1 m apart. The number of points for which $|E_{tot}|=0$ is

A) 0

B) 1

C) 2

D) 3

E) NOTA

A +1C charge and a +2C charge are placed 1 m apart. The number of points for which $|E_{tot}|=0$ is

A) 0

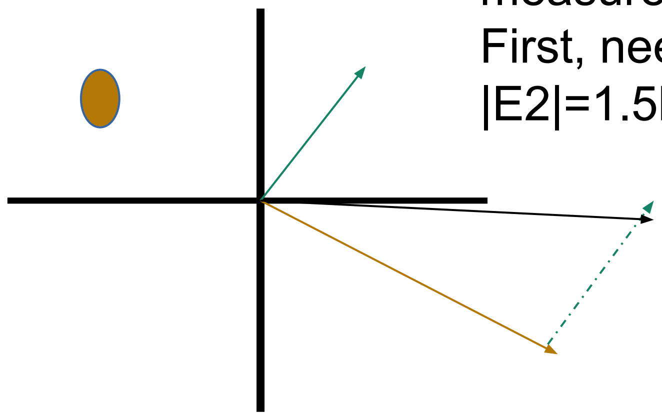
B) 1

C) 2

D) 3

E) NOTA

Source charges Q1=-2C (x,y)=(2,3) and Q2=+1.5C (x,y)=(-2,1). $E_{net}(0,0)$=?



- Graphically: Add two vectors; E1 points directly away from Q1, with tail at measurement pt (0,0); E2 points directly towards Q1, with tail at origin. First, need magnitudes (for numerical addition, as well): |E1|=2k/13; |E2|=1.5k/5, so |E2|~2|E1| => resultant roughly colinear with x-axis

Numerically: |E1|=2k/13; |E2|=1.5k/5,
$E_{1,x}$=(2./13.)*2./sqrt(13.); $E_{1,x}$=+0.085k; $E_{1,y}$=+0.128k;
$E_{2,x}$=+0.268k; $E_{2,y}$=-0.134k. Now add the x-components to get $E_{x,total}$ and $E_{y,total}$

E_{net}=is a vector with (Ex,Ey) = (0.353k,-0.006k);
checks out with graphical!. Net magnitude=0.3531 kN/C

NOTE: Field exists (and is calculable) at every point in space! Now we put a second charge at origin, and can calculate the force on that charge. E.g. Q3=-3C at origin; Force=3*0.3531 kN/C in magnitude, points OPPOSITE direction of net electric field!

Electric Potential (Volts):

Electric analog of `height': defines PE, and also direction of decreasing PE. $\Delta(PE)=mg\Delta h$; $\Delta(PE)=q\Delta V$

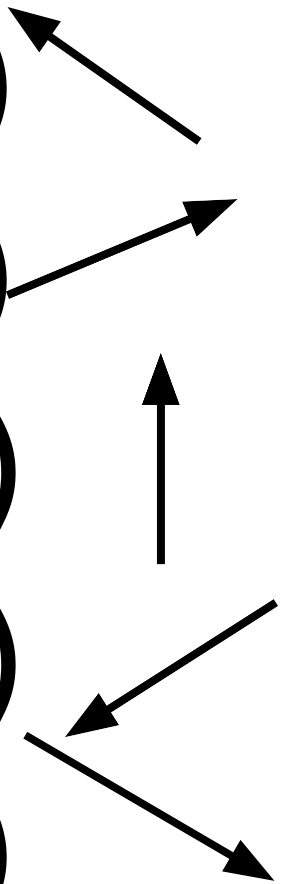
In cases where a mass or charge moves, the work done by the field (grav or electrical) is negative of ΔPE

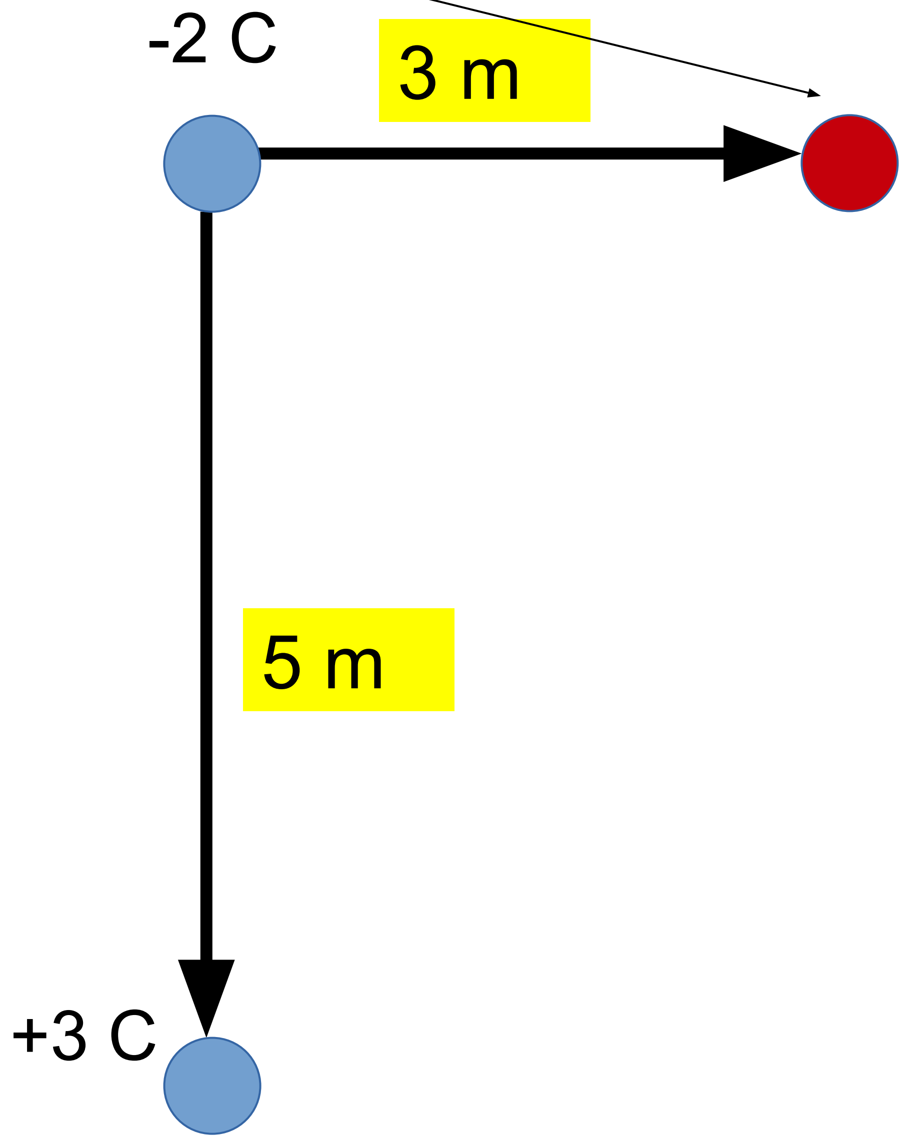
For source charge Q, the potential a distance r away is: $V=kQ/r$.

Positive charges +q spontaneously move from high-potential to low-potential (like masses move from large height to sea level); -q spontaneously move in the opposite direction!

The direction of acceleration of a q=-0.2 C charge placed at A is closest to

A)
B)
C)
D)
E)





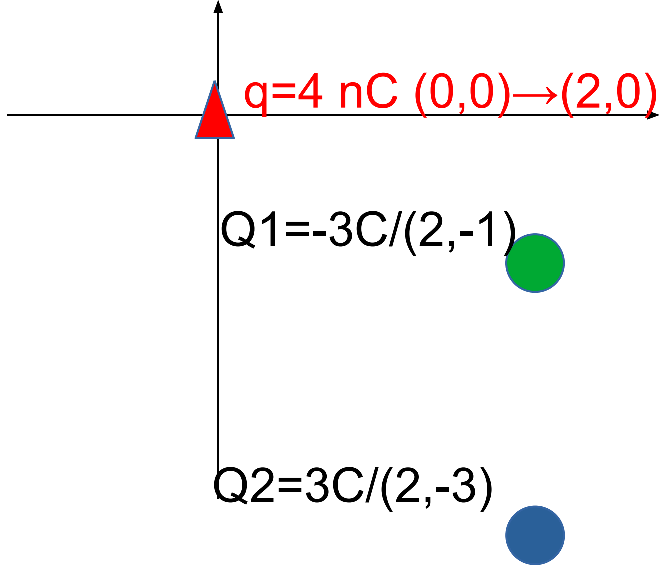
Owing to F_E, the -0.2 C charge q accelerates, eventually reaching some point B. How does the PE of q at B compare with its initial PE?

A) PE(B)<PE(A)

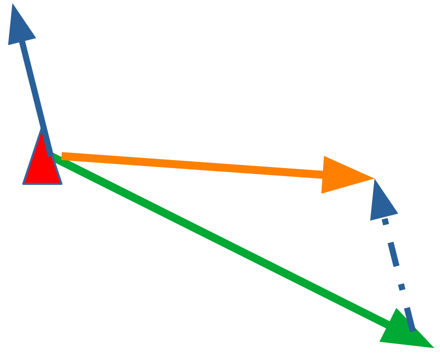
B) PE(B)>PE(A)

C) PE(B)=PE(A)

D) Not enough information



1) E at origin: |E1|=3k/5, towards Q1 (neg. source charge); |E2|=3k/13, away from Q2 (pos. source charge), so vectors in ratio 0.6:0.23~2.6: (resultant in orange)



Since test charge q is positive, this is also the direction along which the charge accelerates (if q<0, moves in opposite direction)!

Now calculate change in potential ($\Delta V=V_f-V_i$) and change in electrical potential energy (=qΔV) in process of moving from (0,0)→(0,2). The change in PE is equal in magnitude, but opposite in sign, to the work done by the external electric field due to the source charges, although it is NOT necessarily the total work done on the charge (which is always given by $W_{tot}=\Delta(KE)$).

$\Delta V=kQ/r_f-kQ/r_i$; for Q1: -3k*(1/1-1/sqrt(5)), for Q2: 3k*(1/3-1/sqrt(13)) – note sign of Q!
Adding: ΔV=-1.49k Volts.
Change in electrical PE=qΔV=4e-9*9e9*(-1.49)=-53.64 Joules.
Work done by electric field=-ΔPE=53.64 Joules

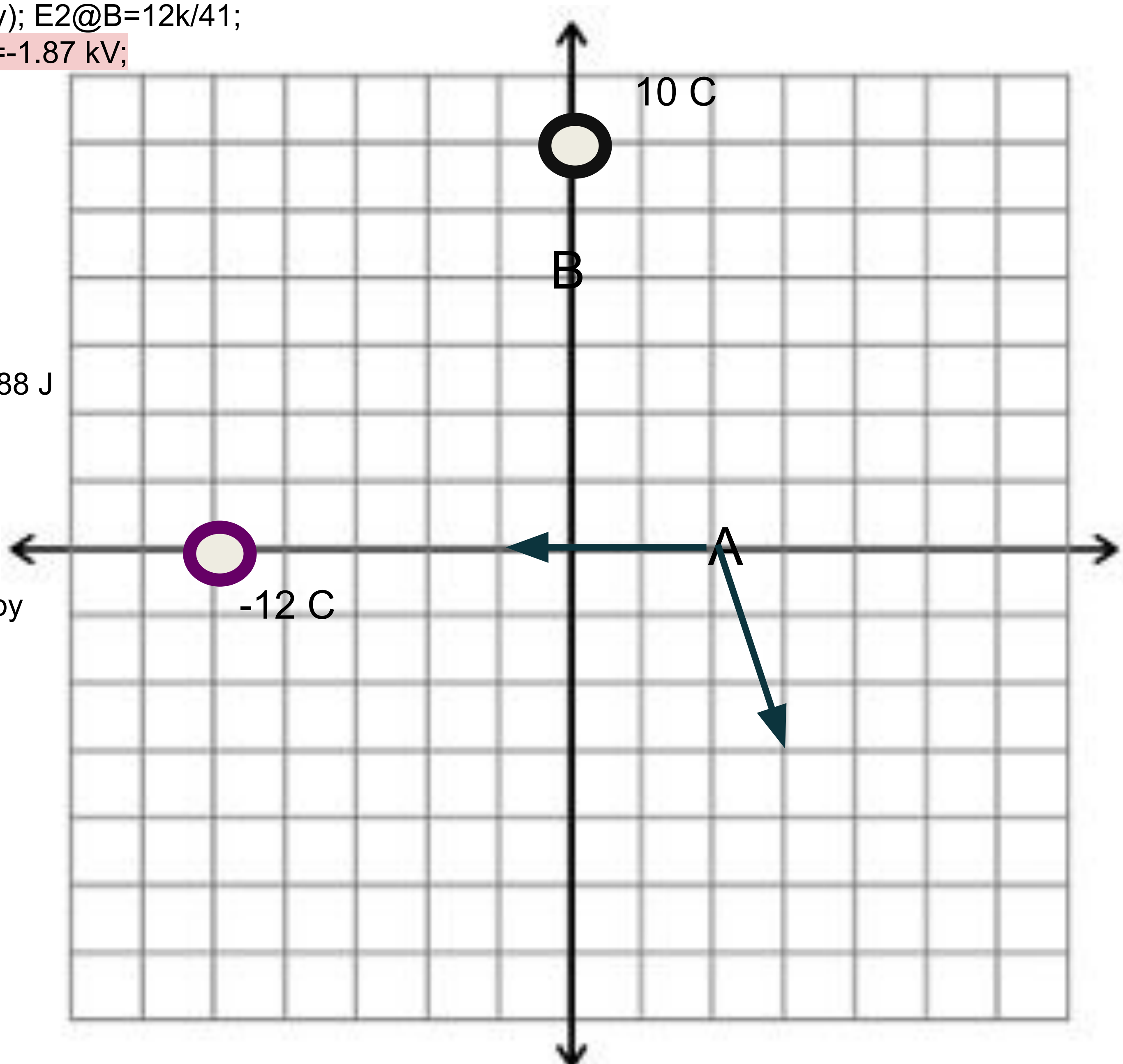
Check against intuition: change in PE should be negative! (since q is being pulled by field (mostly Q1) to a lower potential point - similar to a mass being pulled by earth's gravity from high elevation to low elevation)

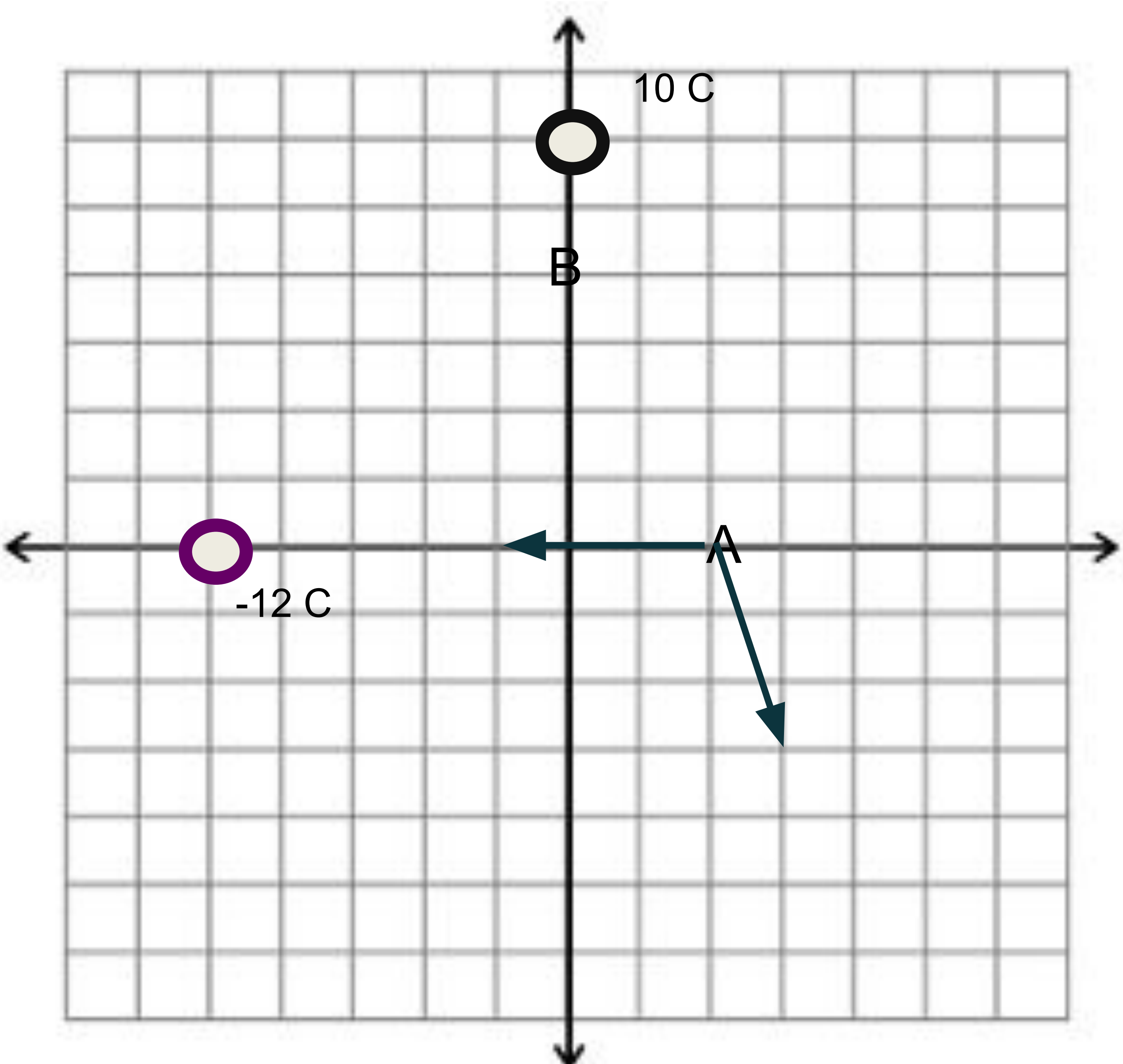
CAP 2

Q1=10 C @ (0,6); Q2=-12 C @ (-5,0); A@(2,0)->B@(0,3).
E1@A=10k/40; E_{1x}=(10k/40)*2/sqrt(40); E_{1y}=(10k/40)*6/sqrt(40)x(-1); E2@A=12k/49 x (-1); E_{2x}=E2;
$E_{x,net}$@A=(10./40.)*(2/sqrt(40.))-(12./49.)=-0.166k N/C; $E_{y,net}$@A=-(10/40.)*6/sqrt(40.)=-0.237k N/C; to determine angle wrt x-axis: tanθ=(Ey,net/Ex,net), so θ=atan(-0.237k/-0.166k), or θ=55 degrees
V1@A=10k/sqrt(40)=1.58 kV; V2@A=-12k/7=-1.71 kV;

E1@B=10k/4=2.5k V; E_{1x}=0; E_{1y}=10k/4 (-y); E2@B=12k/41;
V1@B=10k/2=5 kV; V2@B=-12k/sqrt(41)=-1.87 kV;

now move q3=-2e-9 C charge from A->B;
Work is NEGATIVE of change in PE, so:
W1=-1*(q3ΔV1); W2=-1*(q3ΔV2)
W1=2e-9*k*(5-1.58)=61.56 J, with k=9e9
W1>0 since
q3 is moving closer to Q1, consistent with attraction of Q1
W2=2*k*(-1.87-(-1.71))=-0.32 kJ * e-9=-2.88 J
W2 negative
since q3 is moving closer!
(from 7 m away to sqrt(40 m) away)
Now insert values for KE: Take m=4 kg, v(initial)=4 m/s and v(final)=0 m/s,
so W_{total}=-0.5*4*4*4=-32 J, so work done by Agent Orange=-32-61.56-2.88 = -96.44 J




10 C
B
A
-12 C

The electric force from a heavy -10 C charge at (0,0) "pushes" a -2 C charge from (10,0)->(11,0). Using W=|F||d|cosθ, what is the approximate work done on the -2C charge?

A) k Joules

B) 0.5k Joules

C) -0.2k Joules

D) 0.2k Joules

A heavy Q=-10 C at the origin "pushes" a q=-2 C charge from (10,0) to (11,0). Using Δ(PE)=qΔV, re-calculate the (exact) work done by the -10C charge on the -2C charge

A) 0.182k J

B) -0.556k J

C) 0.845k J

D) -0.182k J

E) NOTA

If the mass of the -2C test charge is 4 kg, what is it's velocity as it passes through the point (11,0)?

A) 28.6 km/s

B) 12.88 km/s

C) 155.2 m/s

D) 33.9 m/s

E) NOTA

Bad Trip Records: Sisyphus pushes a 100 kg boulder up Mt. Oread (80 m along the base and making an angle of 36.9° wrt horizontal). When he reaches the top, the boulder has v=10 m/s. What is W_{net} done on the boulder, assuming it starts from rest?

A) 5000 J

B) -58800 J

C) 63800 J

D) -63800 J

E) NOTA

Sisyphus pushes a 100 kg boulder up Mt. Oread (80 m along the base and making an angle of 36.9° wrt horizontal). When he reaches the top, the boulder has v=10 m/s. What is $W_{Sisyphus}$?

A) 5000 J

B) -58800 J

C) 63800 J

D) -63800 J

E) NOTA

Given a -4 C source charge at (-4,3) and a 2nd source +2 C charge at (0,-5); what is the work done by someone who pushes q=-2 C from `far away' to (0,0), assuming it starts and ends with v=0?

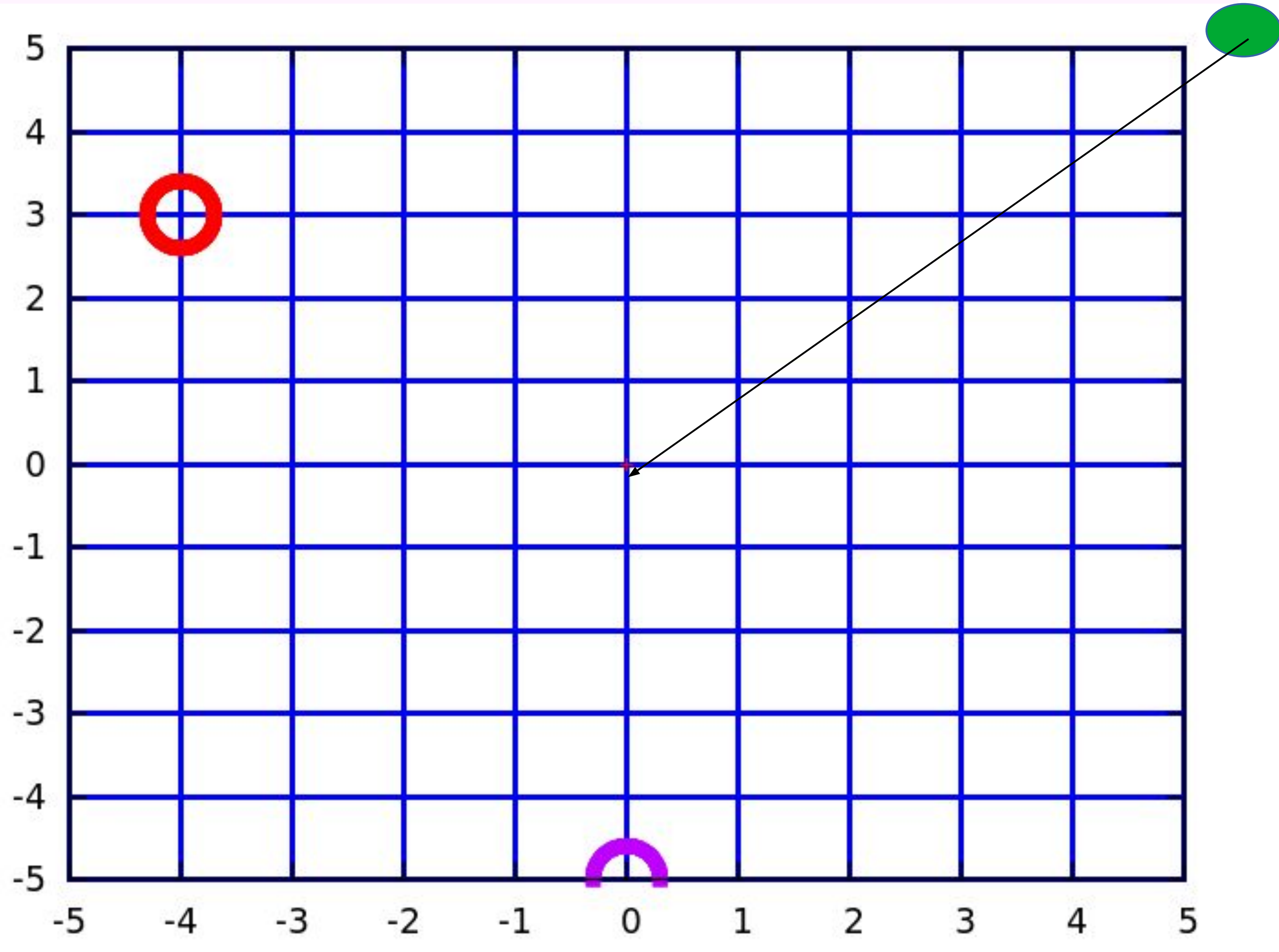
A) -0.8k J

B) 0.8k J

C) 0.4k J

D) -0.4k J

E) NOTA



Given a 1 mC source charge at the origin; a 4 kg. -2μC charge is pushed by Strelka from (3,0)→(2,0), after which it has a velocity of 4 m/s. In so doing, $W_{Strelka}$ is:

A) 29 J

B) 35 J

C) 32 J

D) 3 J

E) NOTA

Calculation of electric potential and meaning of electric field maps

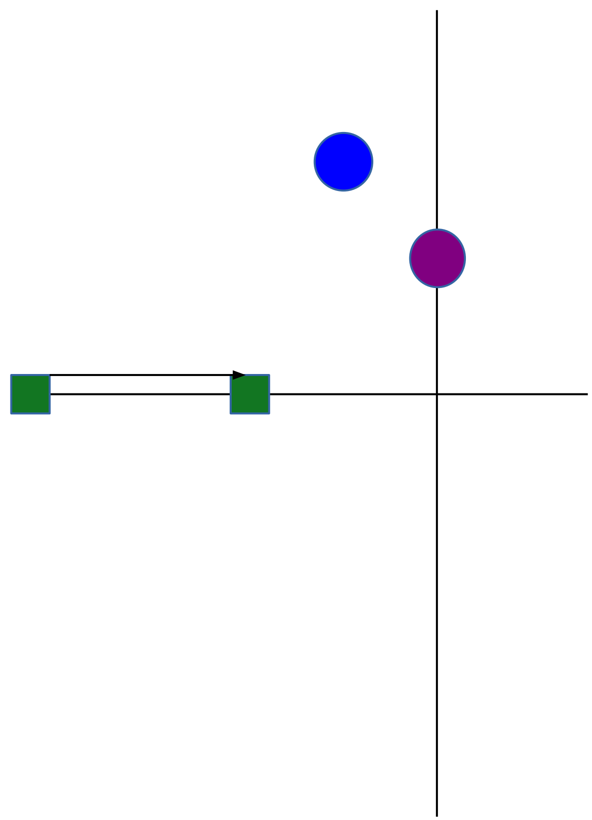
a) construct a problem with 3 non-linear charges such that the potential at the origin is zero. Numerically find E(0,0)

b) construct a problem with 3 charges (not in a line) such that one component of the electric field (E_x or E_y) is zero at the origin. Calculate the potential at the origin. c) problem following example XXX in text.

To make a potential/elevation map, we first probe the force/field, then draw contours perpendicular to force/field lines.

CAP3:

$Q1=-2C$ (-1,3); $Q2=+3C$ (0,2). $q=4x10^{-9}C$ (-4,0)→(-2,0); m=2 kg. v_i=2 m/s; v_f=4 m/s



What we know:

a) $W_{tot}>0$, since $v_f>v_i$: $W_{tot}=0.5m(16-4)=12J$,

b) To get Work done by electric field, we'll calculate the change in PE of the charge, then use $W_{field}=-\Delta PE$, with $\Delta PE=q\Delta V$.

To calculate ΔV, taking into account both Q1 and Q2: $\Delta V=(V_{f,1}-V_{i,1})+(V_{f,2}-V_{i,2})$; $V=kQ/r$,

So: $\Delta V=k(-2C)*(1/sqrt(10)-1/sqrt(18))$ + $k(+3C)(1/sqrt(8)-1/sqrt(20))=+0.23k$ Volts, so $\Delta PE=8.23$ J,

so work done by field is *negative 8.23 J* (positive charge moves to higher PE)!

So work done by person is 20.23 J, since $12J=W_{agentOrange}+W_{field}$

Connection between electrical potential and electric field; how to predict the path of a charge q3

A ball, starting at point X, would most likely roll

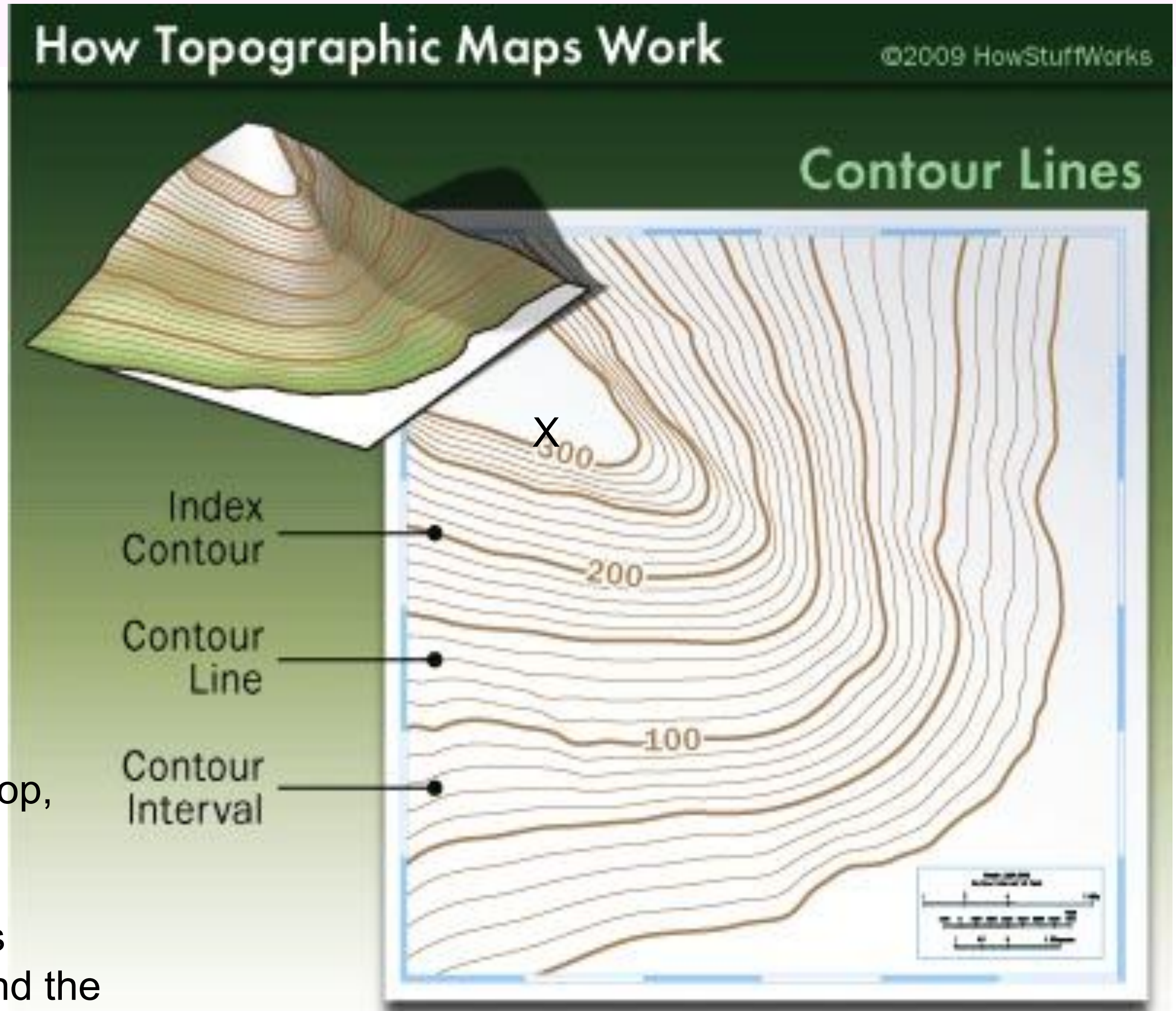
A)

B)

C)

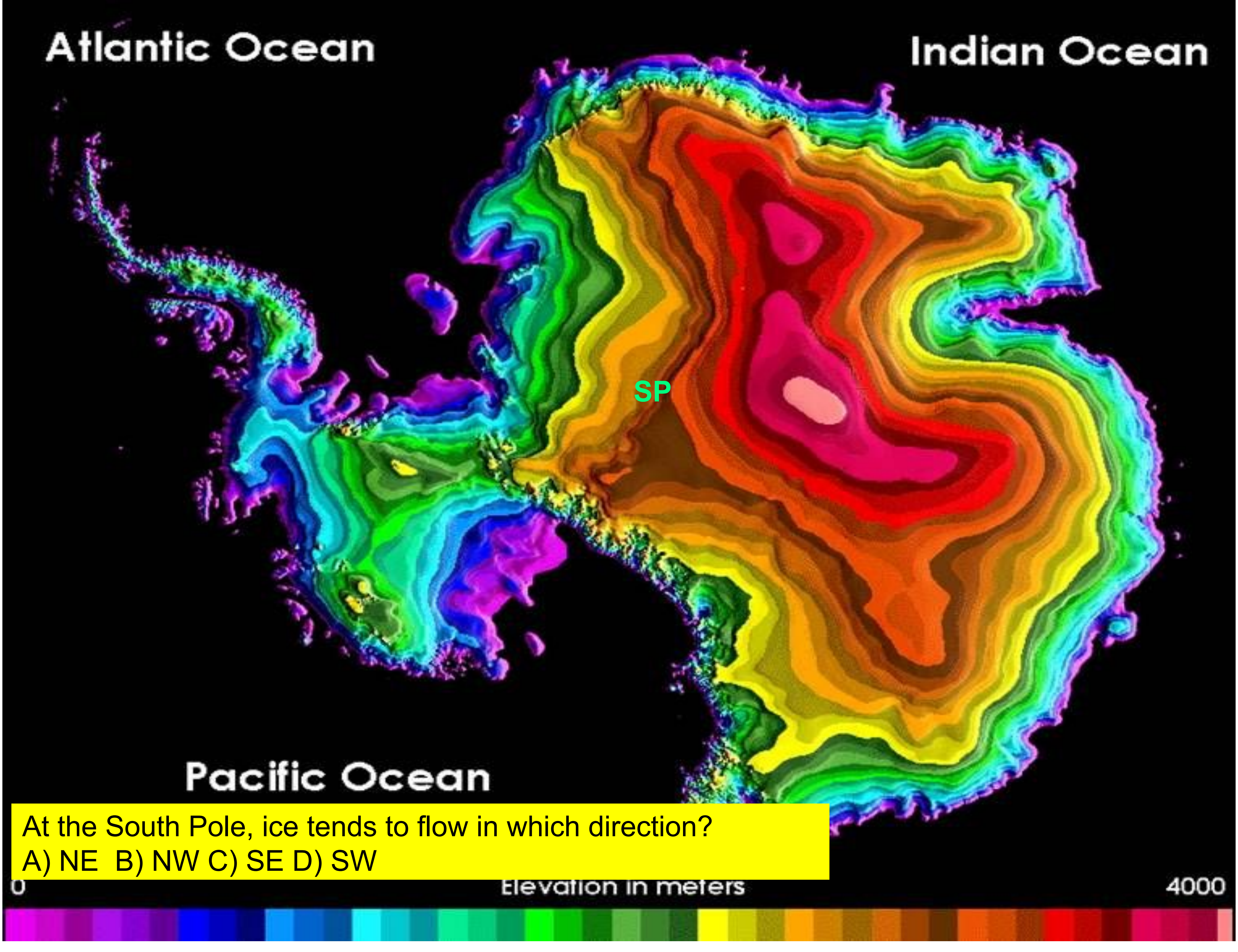
D)

E)



N.B:a) for spherical mountaintop, contours are symmetric!

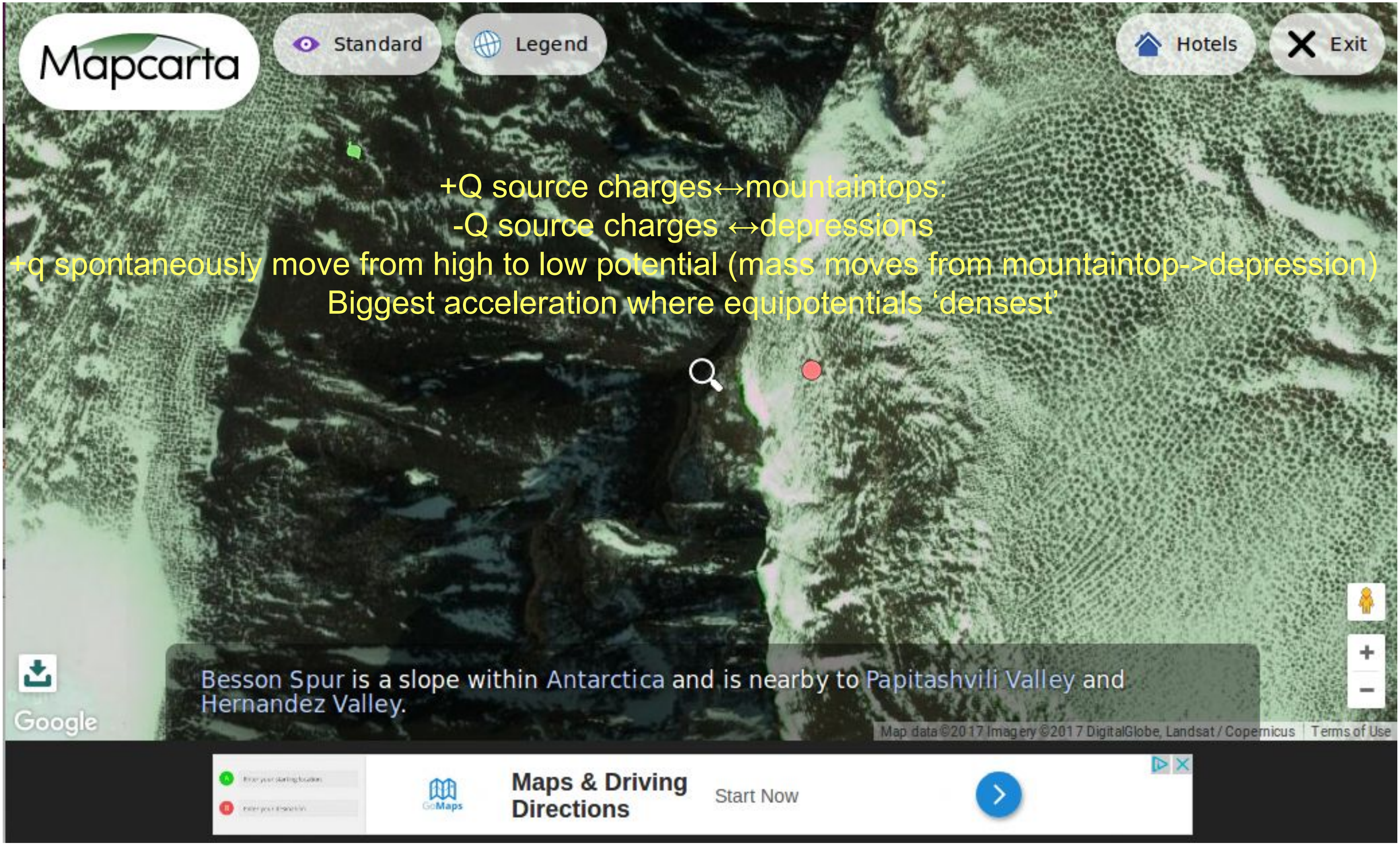
b) analogy not exact since this gravitational example is 3-d and the fields we've considered are 2-d



At the South Pole, ice tends to flow in which direction?
A) NE B) NW C) SE D) SW

GEOGRAPHIC
SOUTH POLE
ROALD AMUNDSEN
DECEMBER 14, 1911
"So we arrived and were able to plant our flag at the geographical South Pole."
ROBERT F. SCOTT
JANUARY 17, 1912
"The Pole. Yes, but under very different circumstances from those expected."

+Q source charges↔mountaintops:
-Q source charges ↔depressions
+q spontaneously move from high to low potential (mass moves from mountaintop->depression)
Biggest acceleration where equipotentials ‘densest’



Analogy b/w voltage and height, E and gravitational fields.

Superimpose an equipotential map on graph paper (x,y coordinate space), labeling the lines with their voltage values. a) at some point in the map, determine the direction of the E-field and estimate the magnitude of the E-field, b) introduce a charge at some point A and specify its initial mass and velocity, now move the charge to point B and also specify its final velocity. What is the work done by the E-field corresponding to your map? How much external work is done on the charge?

Given that E-field strength is indicated by the 'density' of field lines a given distance from a source, what value of charges (left/right) are consistent with the Electric field map shown?

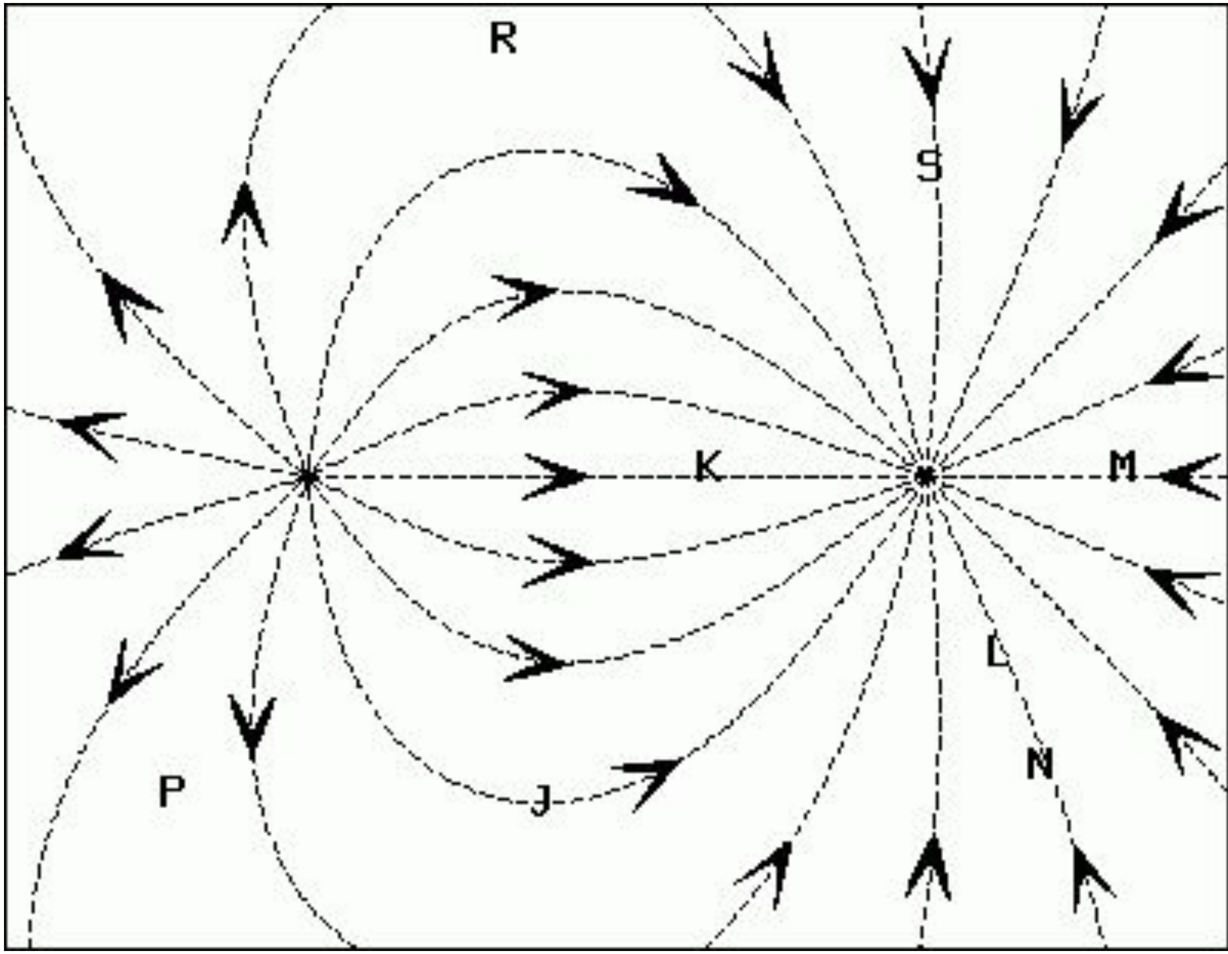
A) -1 C, +2 C

B) +1 C, -2 C

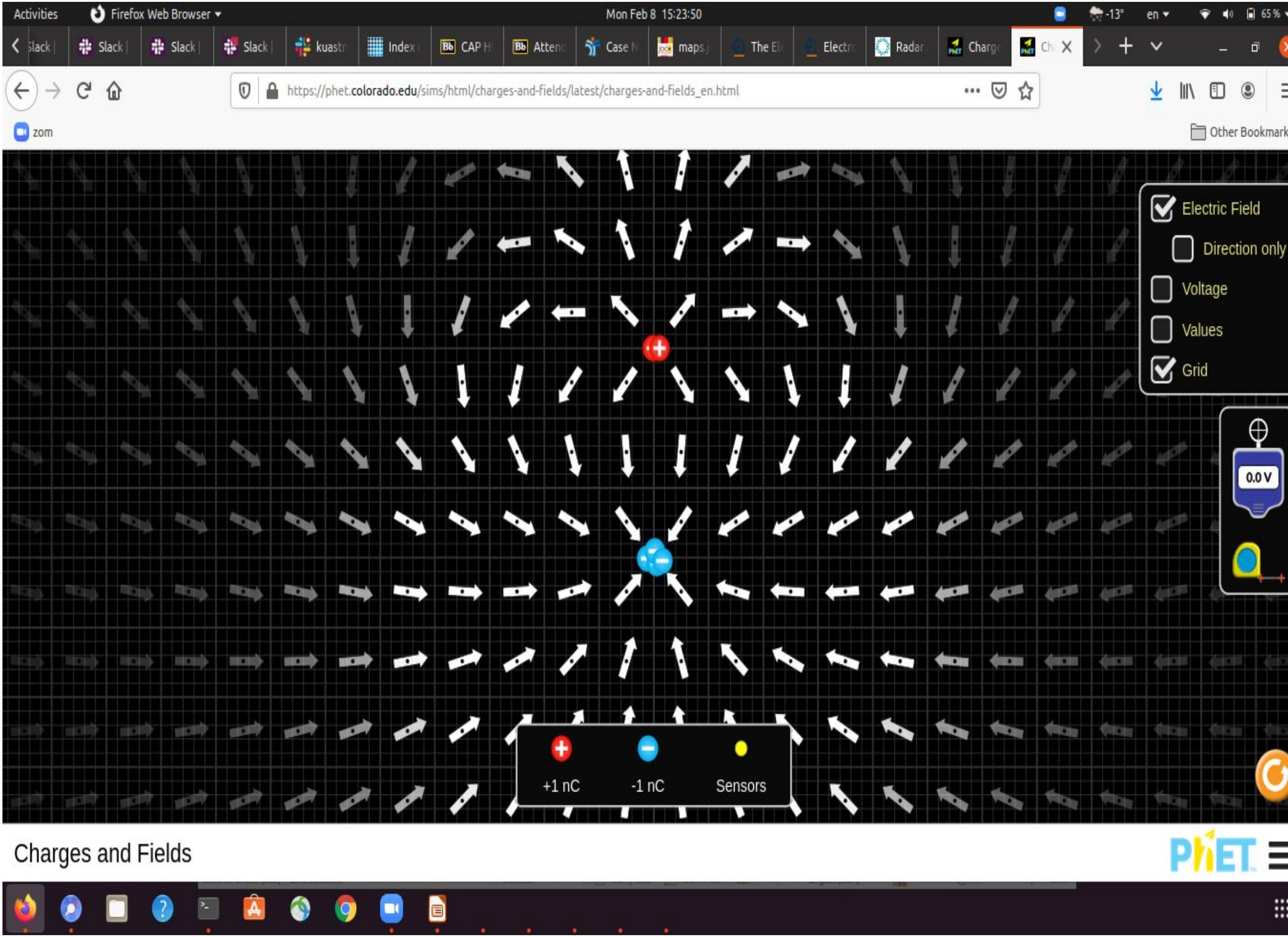
C) -1 C, +1 C

D) +1 C, +1 C

E) -2 C, -2 C



Sketch the `equipotentials'


Activities
Firefox Web Browser
Mon Feb 8 15:23:50
https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html
zom
Other Bookmarks
Electric Field
Direction only
Voltage
Values
Grid
0.0 V
+1 nC
-1 nC
Sensors
Charges and Fields
PhET

From your knowledge of topographical maps, and the analogy between gravity and electricity (E~g and V~h), which statement below is true?

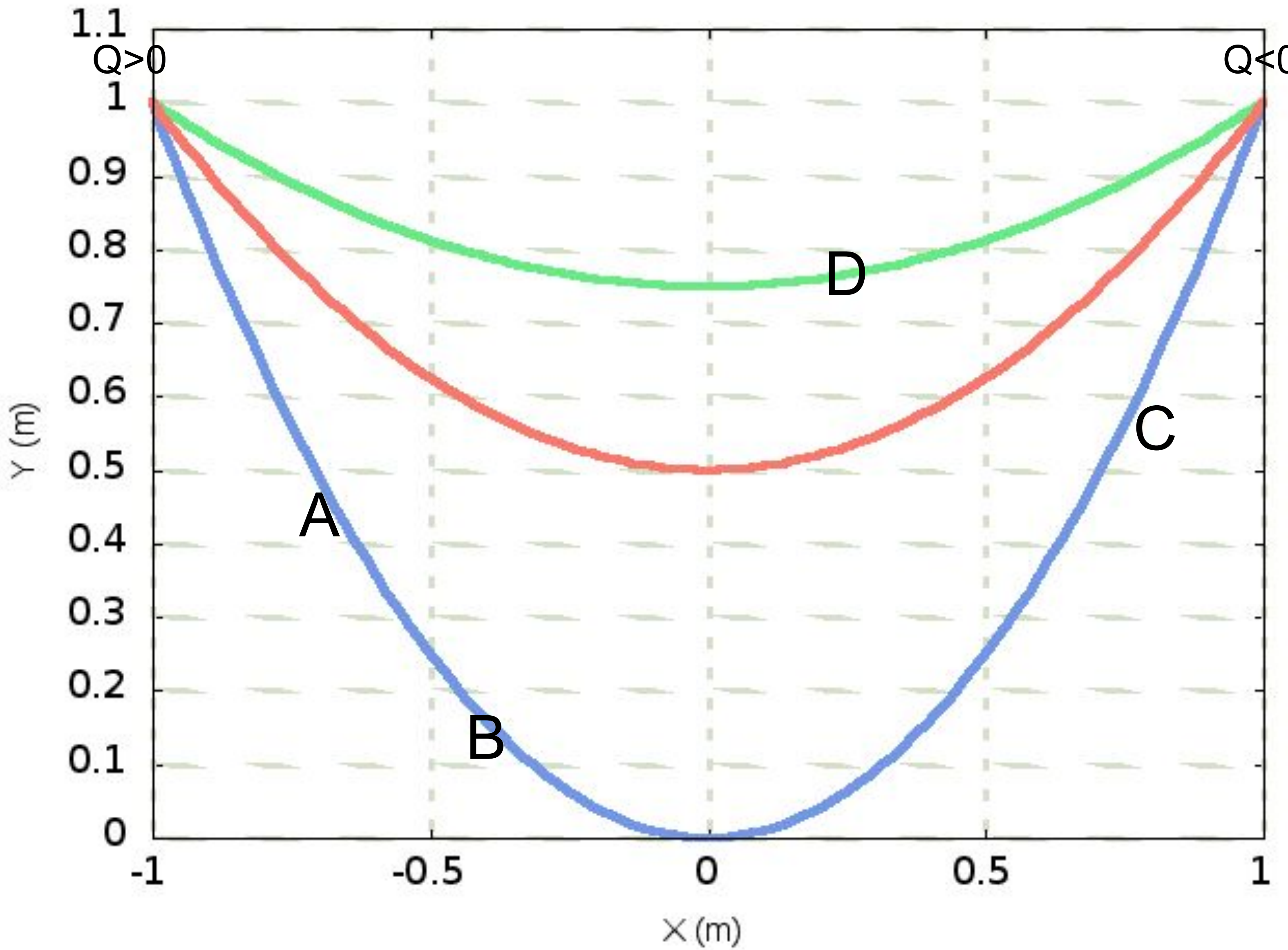
A) The electric field vector is tangent to the equipotentials.

B) The electric field vector points perpendicular to the equipotentials, in the direction of increasing potential.

C) The electric field vector points perpendicular to the equipotentials, in the direction of decreasing potential.

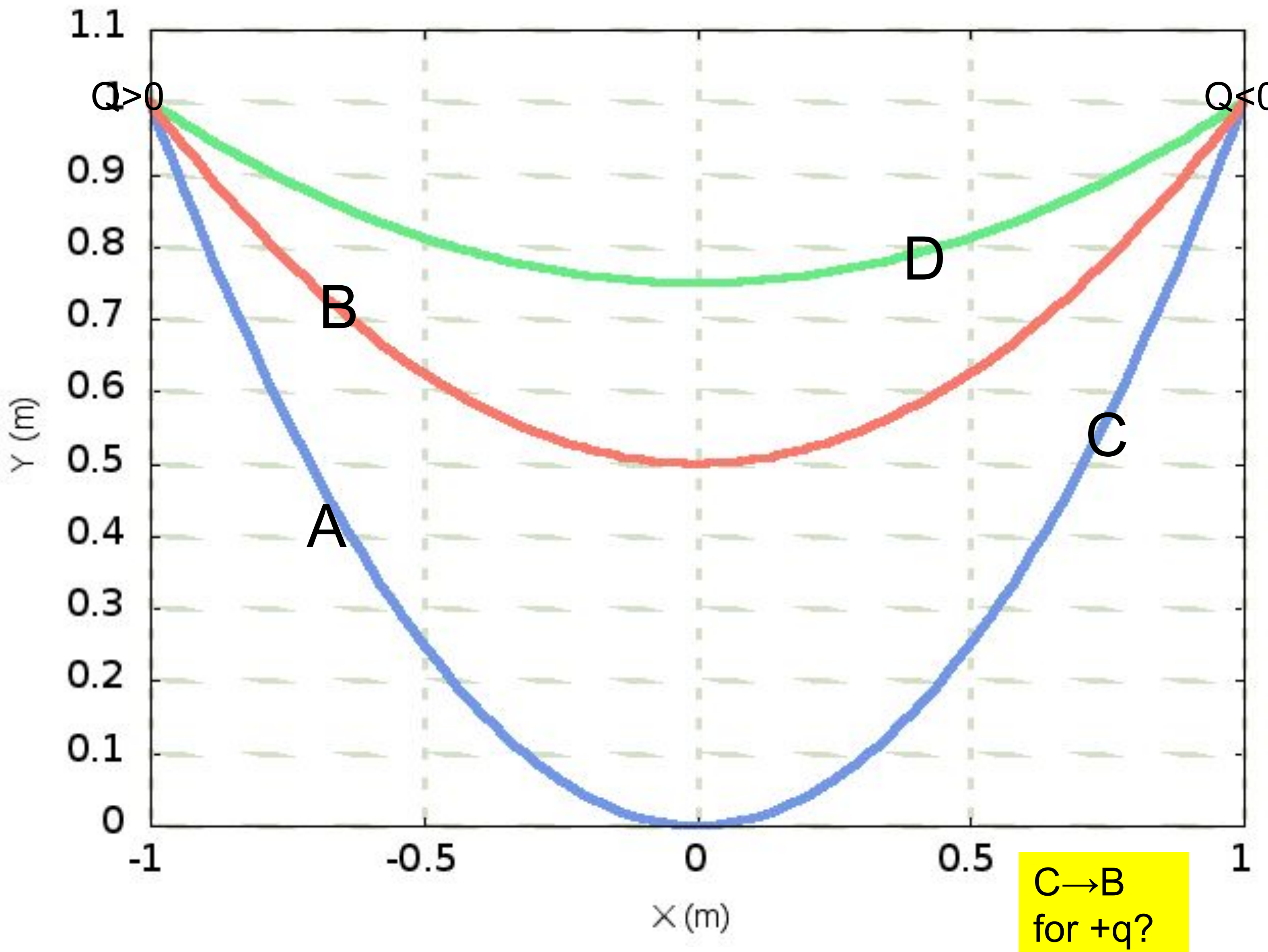
D) NOTA

Given the E-field map shown, draw the equipotentials starting at the points A, B and C, if $Q_{left}>0$ and $Q_{right}<0$



In moving from A→D, the PE of a negative charge (how does -q 'want' to move and thereby gain KE?)

A) Increases
B) Decreases
C) is constant



C→B for +q?

A -6C *source* charge is at the origin. The change in potential, and ΔPE, when a -2 C charge is moved from (x,y)=(2m,0) to (0,-3m) is:

A) 3k V, 3k J

B) 6k V, k J

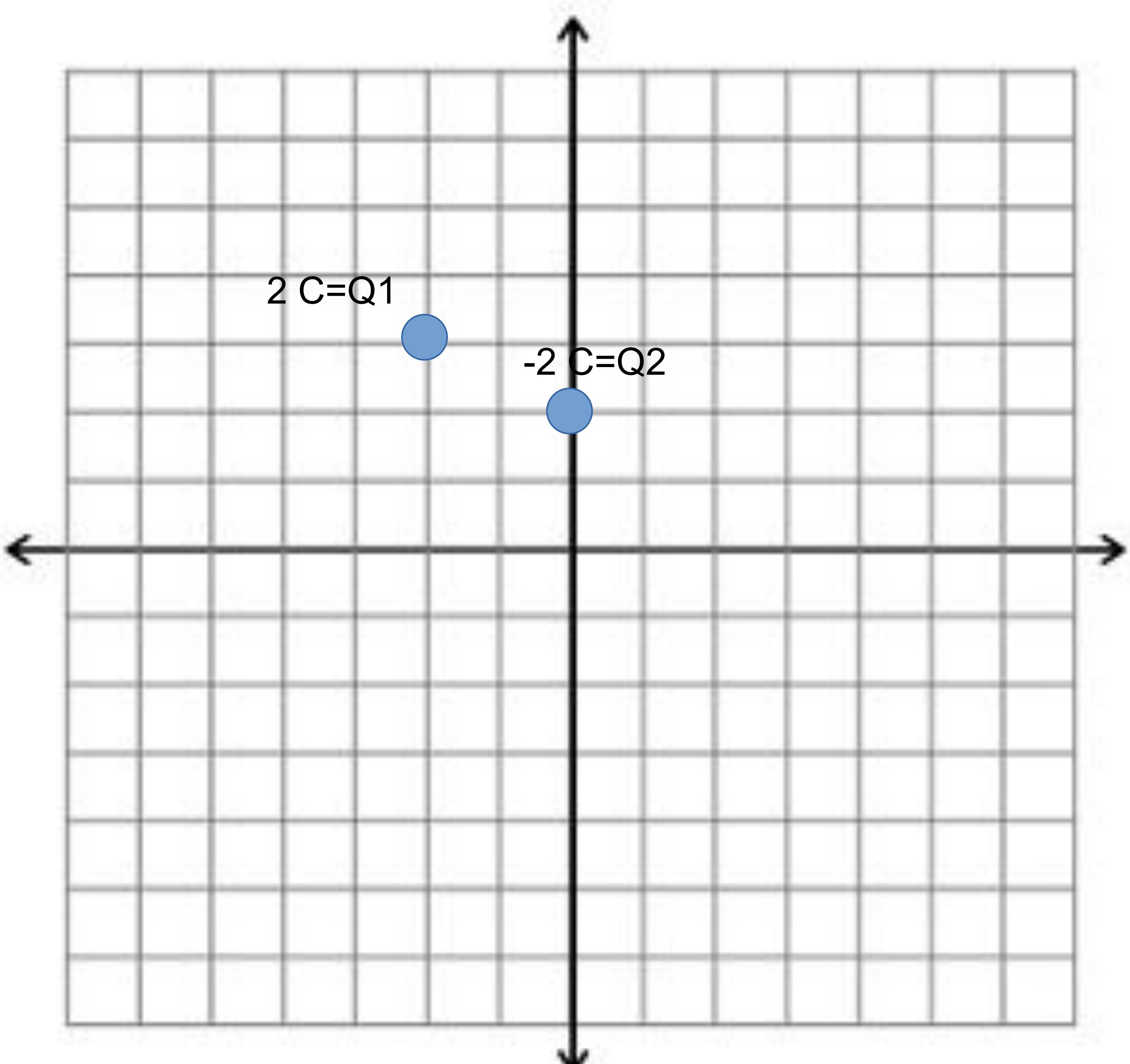
C) -k V, -2k J

D) k V, -2k J

E) NOTA

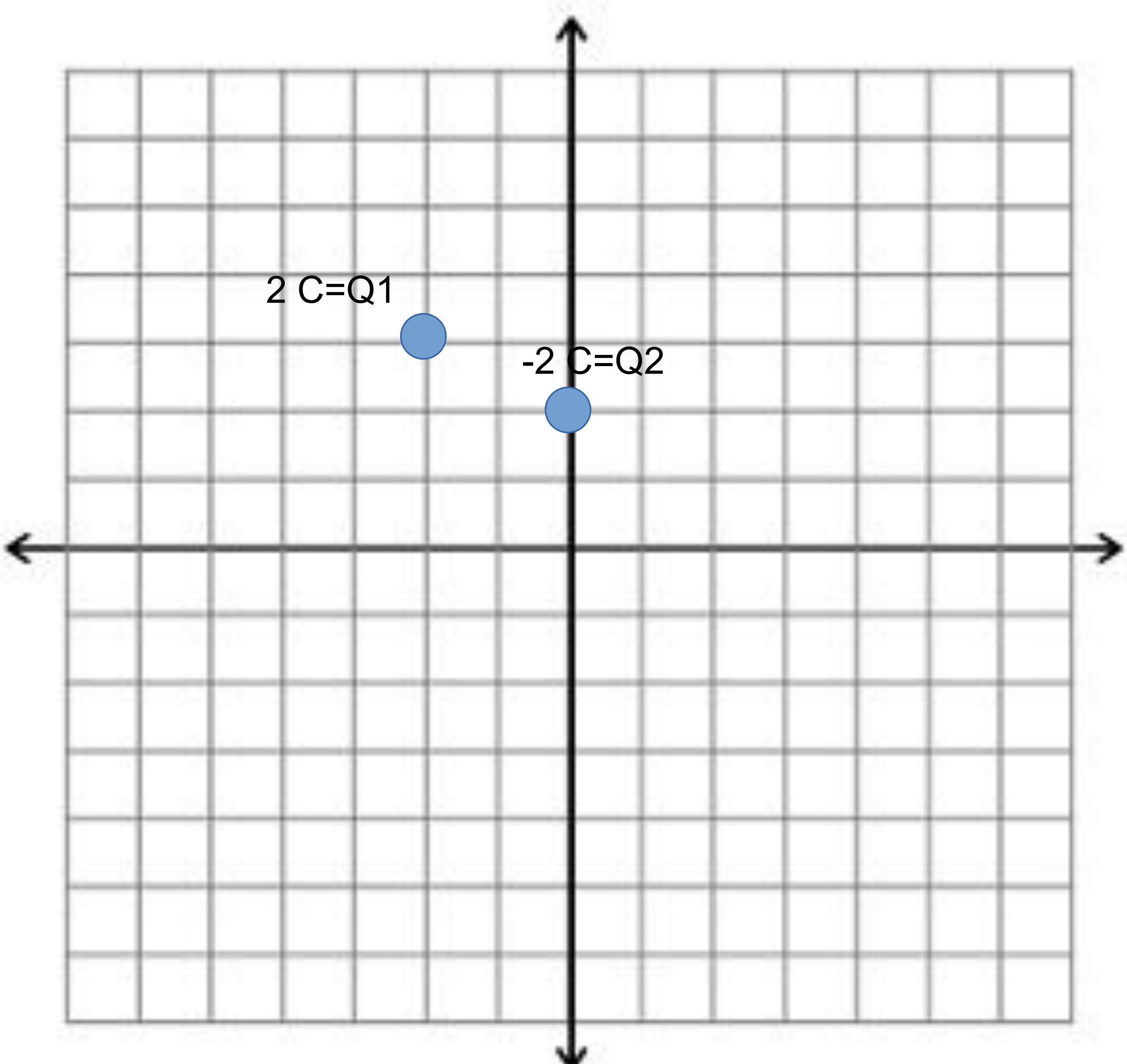
A charge q=-0.1 C is placed at the origin and released. The work done on q=-0.1 C subsequent to its release is:

A)W1>0, W2<0
B)W1>0, W2>0
C)W1<0, W2<0
D)W1<0, W2>0
E)NOTA



realizing that positive test charges q tend to move from higher to lower potential (while negative test charges q tend to move from lower to higher potential), what is the relative potential at (x,y)=(0,0) vs. (x,y)=(-1,-2)? Check your answer numerically

A)V(0,0)>V(-1,-2)
B)V(0,0)<V(-1,-2)
C)V(0,0)=V(-1,-2)



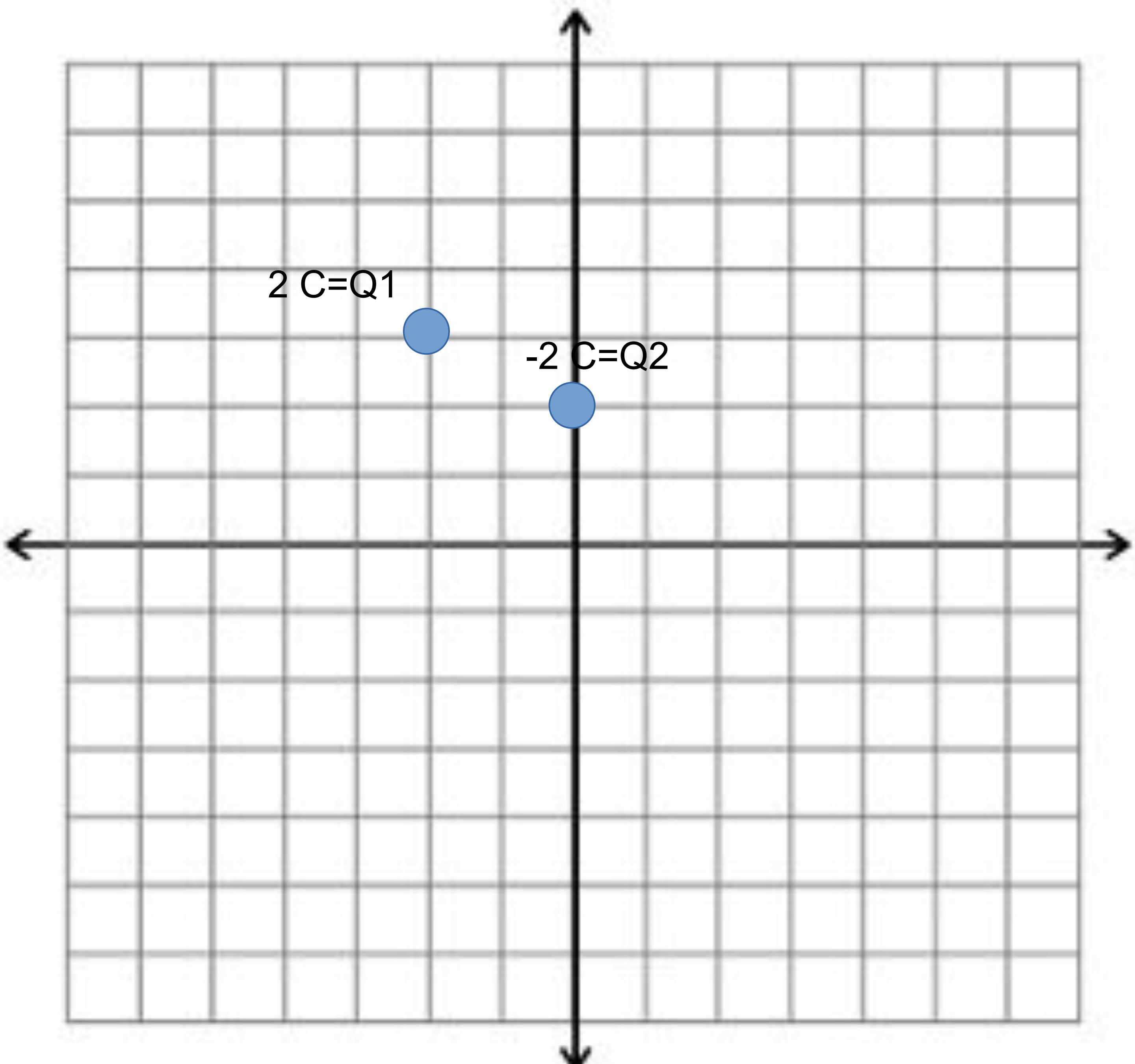
The E-field direction at (0,0) is (check your graphical answer numerically!):

A) NE

B) NW

C) SE

D) SW



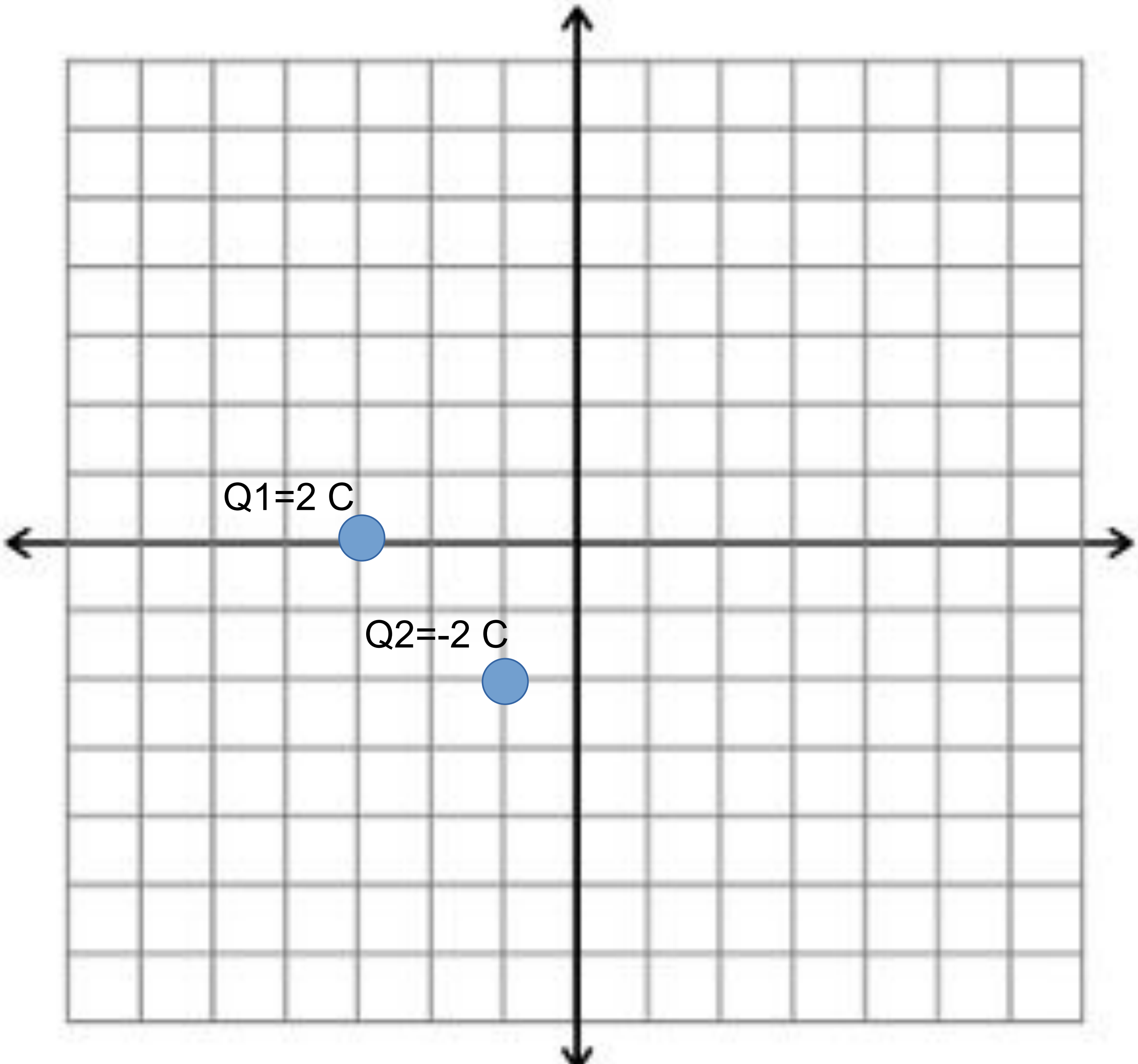
A -0.1 C charge q is now placed at the origin, and released. Given that the force on q is given by F=qE, what is the direction of acceleration of q?

A) NE

B) NW

C) SE

D) SW



What if q was +0.1C?

Given the two source charges shown. The number of points along x- for which $|E_{tot}|=0$ and also $V_{tot}=0$ is, respectively:

A) 1,2

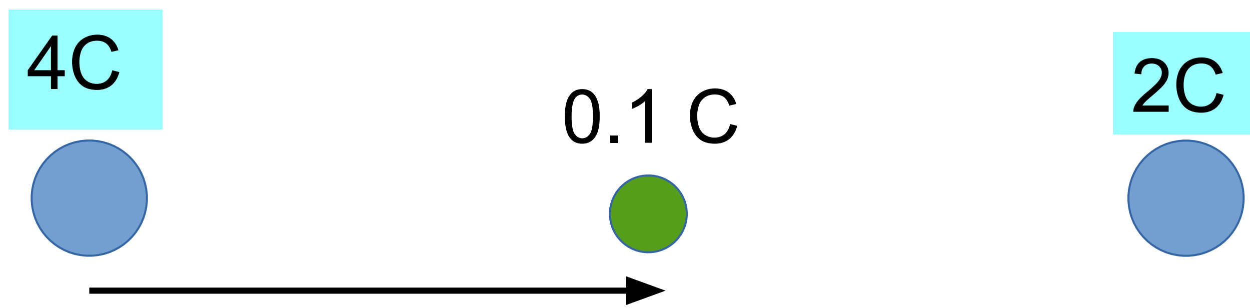
B) 1,1

C) 2,1

D) 2,2

E) NOTA

A second +2C charge is placed 2 m to the right of the 0.1C charge, and the 0.1C charge released from x=0. At what point does the charge change direction?



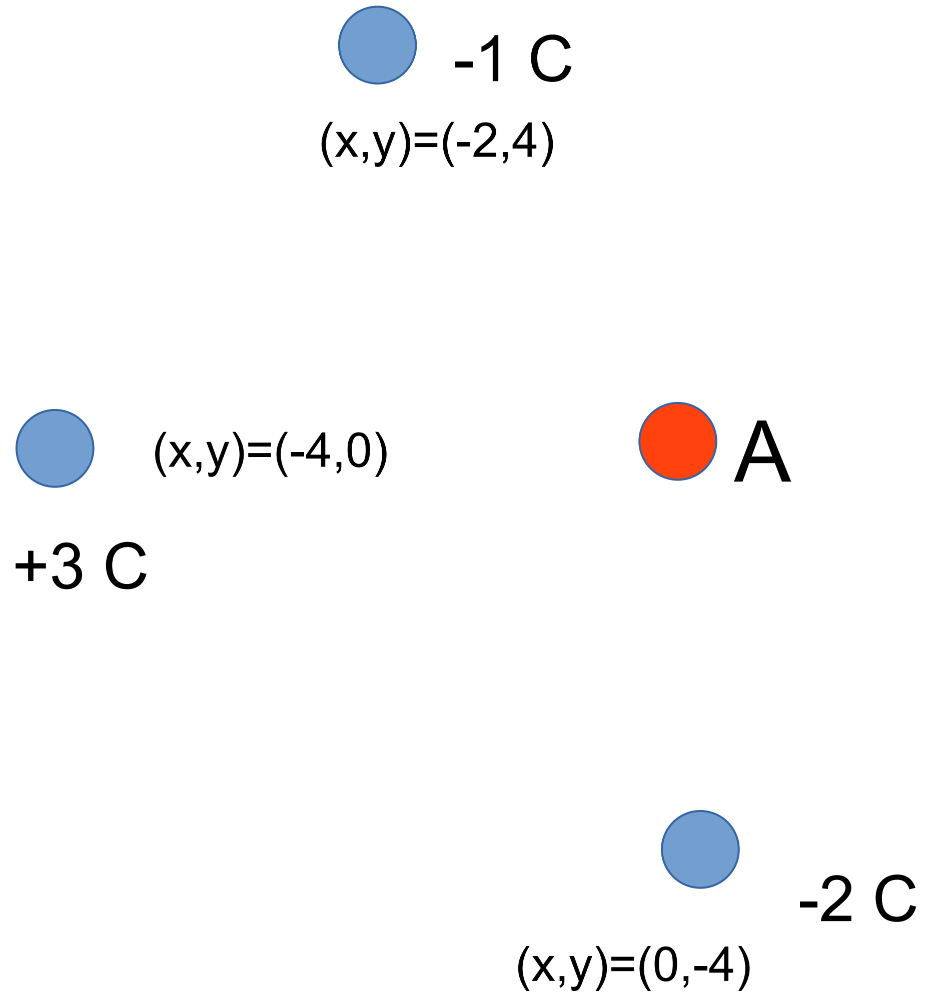
A) X=1 m

B) X=0.345 m

C) Not finished yet….

The voltage (=`potential’) at point A (0,0) is:

A) 0k V
B) 0.337k V
C)0.0143k V
D)0.0264k V
E) NOTA



In the previous problem, consider 3 pts P_0, P_1, and P_2, which are at y=-1 m, -2 m, and -3 m, respectively. Rank the potentials at the 3 points from most negative to most positive (low to high)

A) $V_0 > V_1 > V_2$

B) $V_0 < V_1 < V_2$

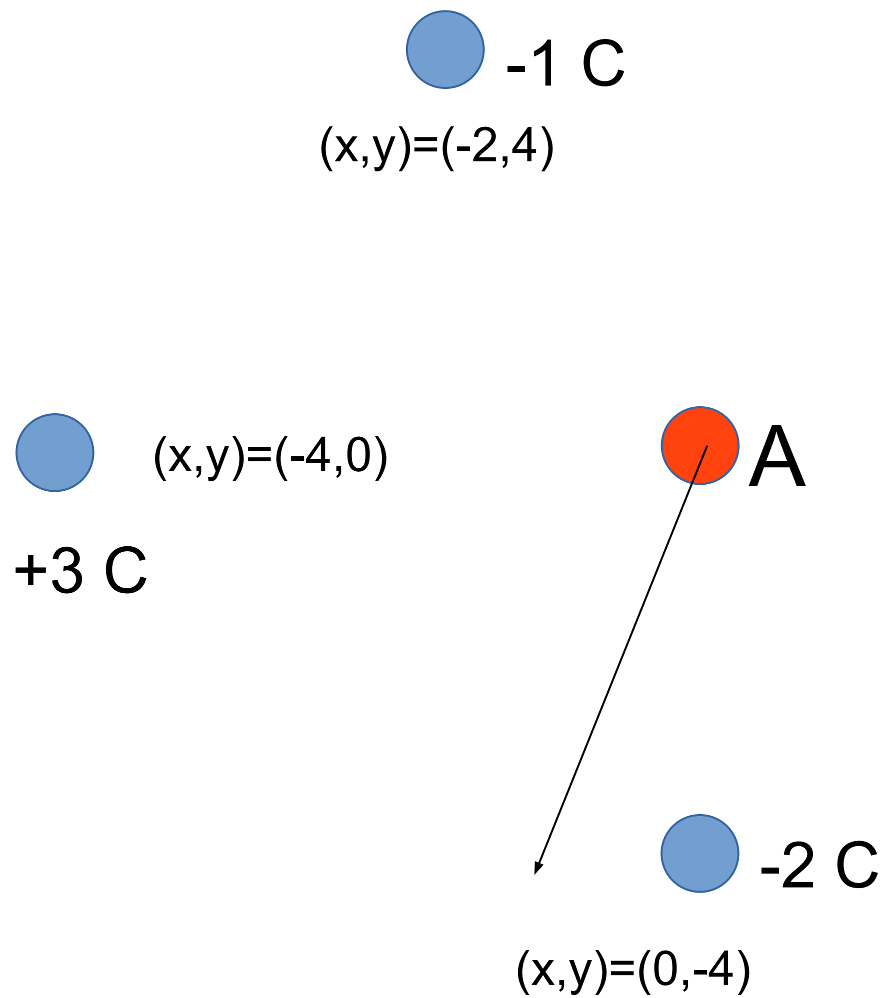
C) $V_1 > V_2 > V_0$

D) $V_1 > V_0 > V_2$

E) NOTA

A -2C charge q is placed at A and moved to (-2,-4). The ΔPE of q is:

A) 0k J
B) 0.337k J
C)0.961k J
D)0.126k J
E) NOTA



Given the E(x) map; what is the final velocity of a 0.48 kg, -2 C charge that starts at x=-2 m and ends at x=6 m?

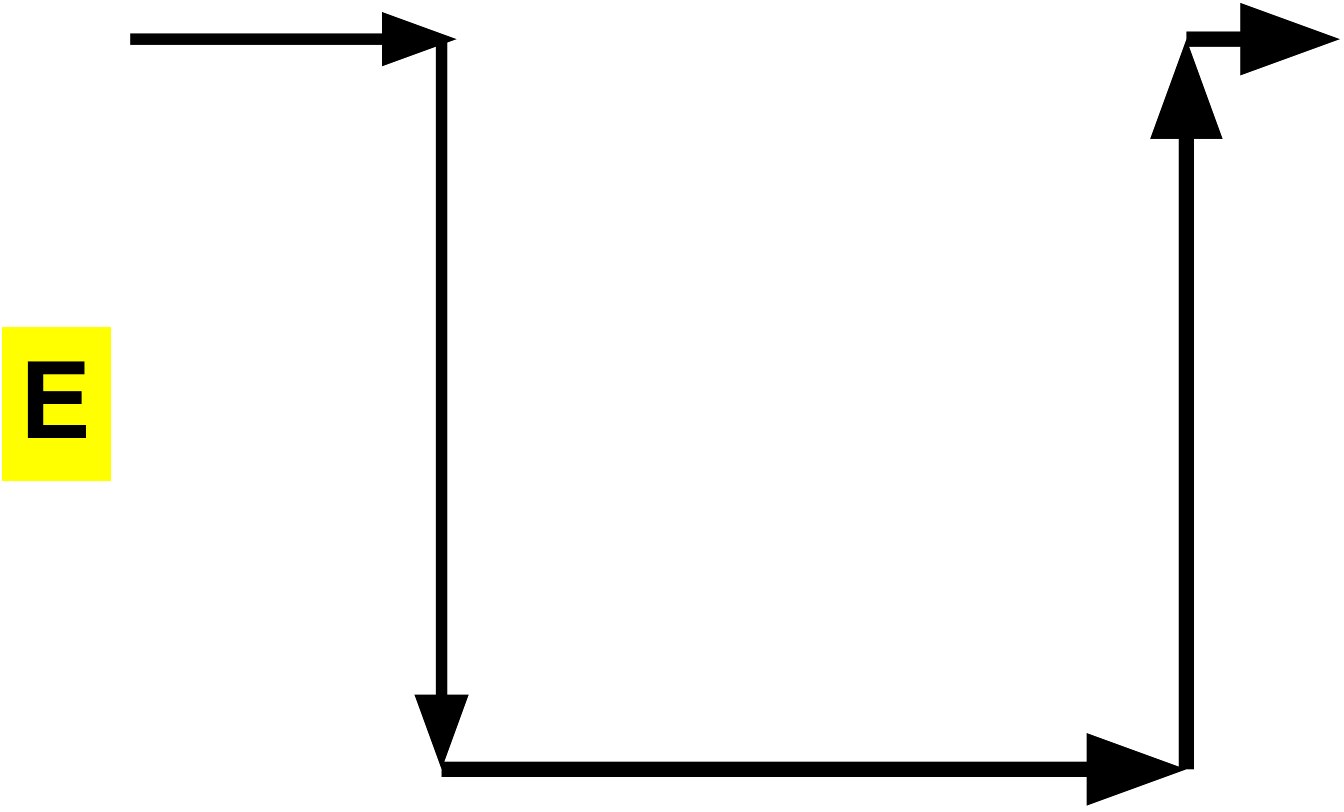
A) 0 m/s

B) 2 m/s

C) 8 m/s

D) 10 m/s

E) NOTA



Three concentric metallic spheres containing charges -2C, +3C, and -C (inner to outer sphere) have diameter 2m, 4m and 6m, respectively. At the point x, the electric field has magnitude and direction

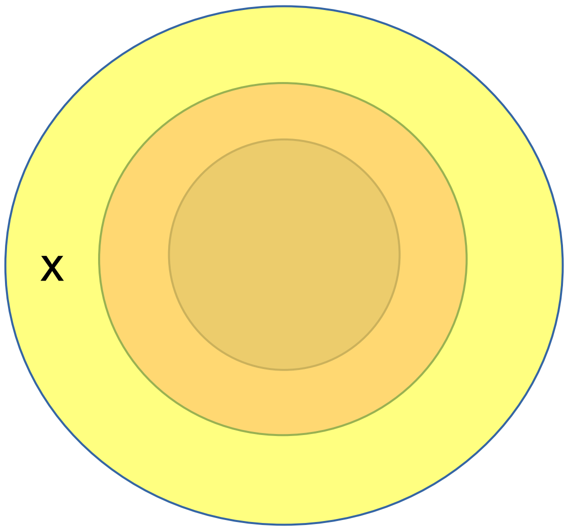
A) k/25; +y

B) k/25; +x

C) 5k/25; +y

D) 3k/25; +x

E) NOTA



Given the graph of potential as a function of position x; the E field values at x=-1m, x=1.5m, and x=4.5m, are closest to:

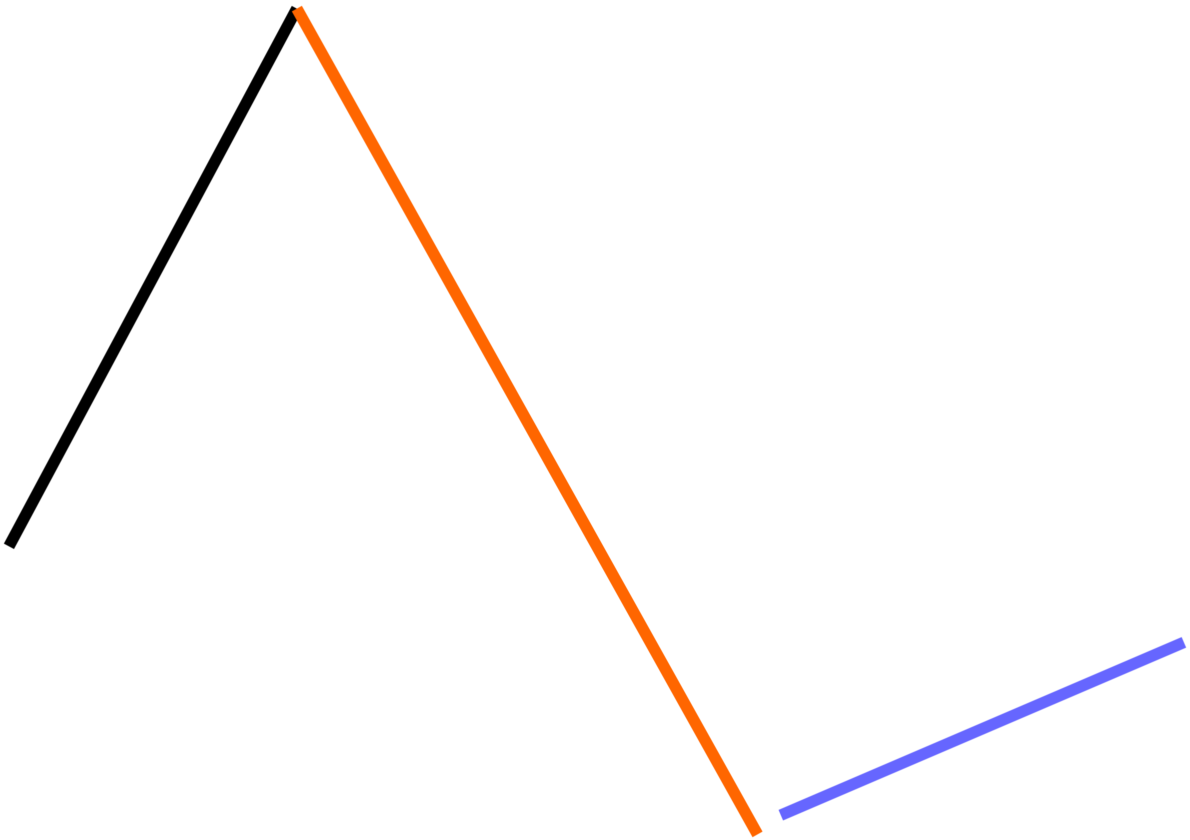
A) 2 V/m, -2 V/m, 3 V/m

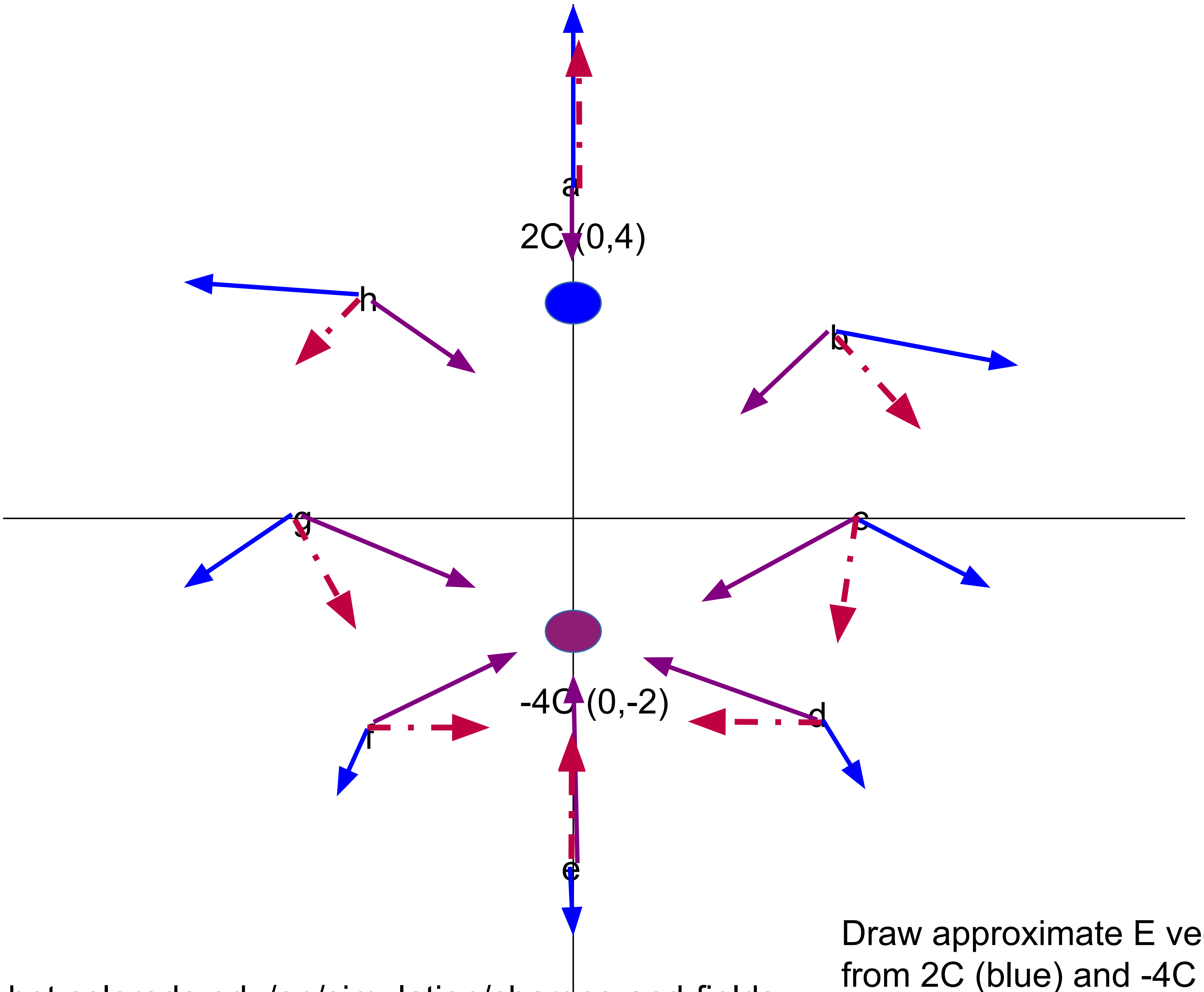
B) -2 V/m, 4 V/m, -5 V/m

C) 4 V/m, -5 V/m, -3 V/m **V**

D) -3 V/m, 3 V/m, -1.5 V/m

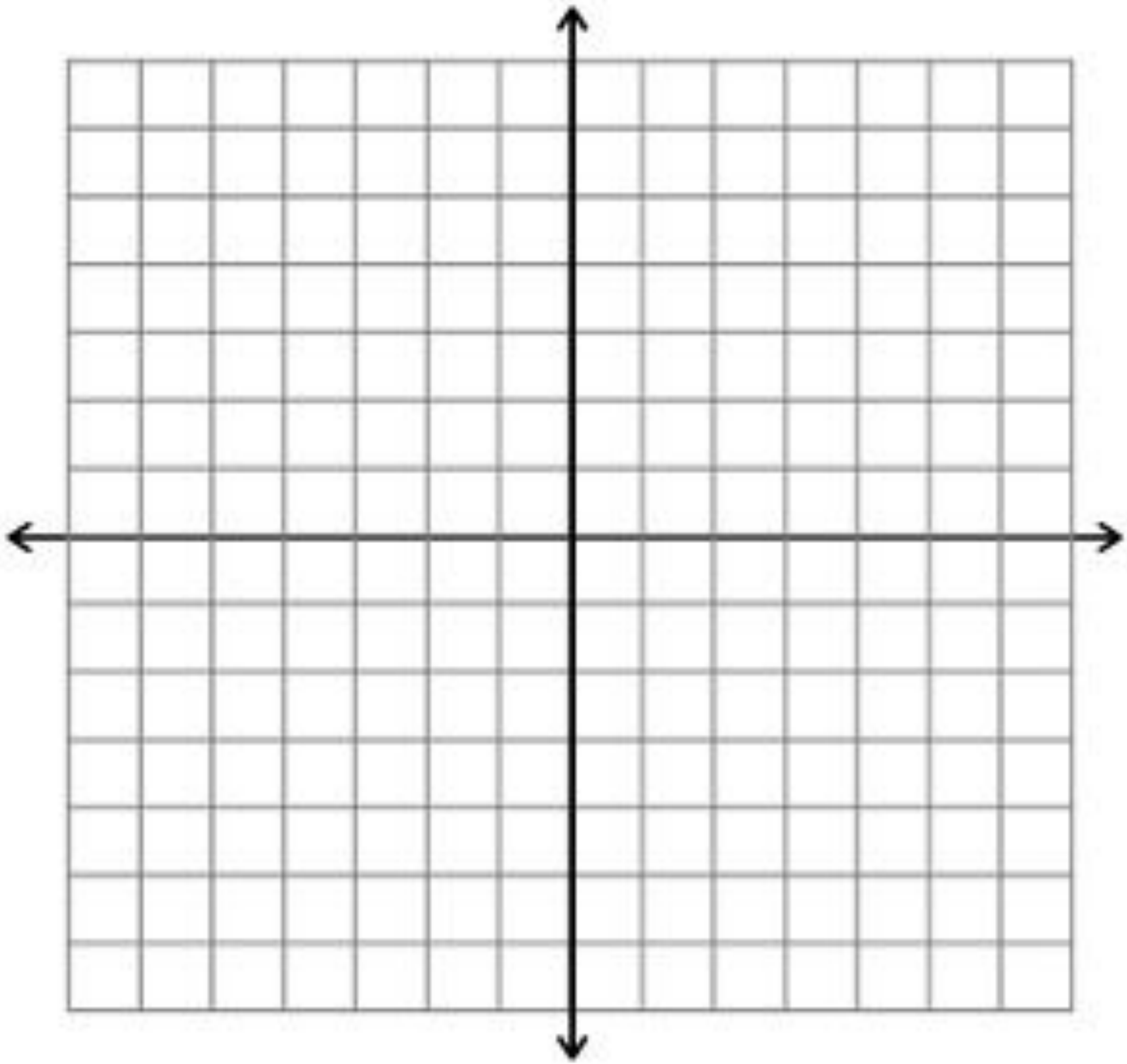
E) NOTA



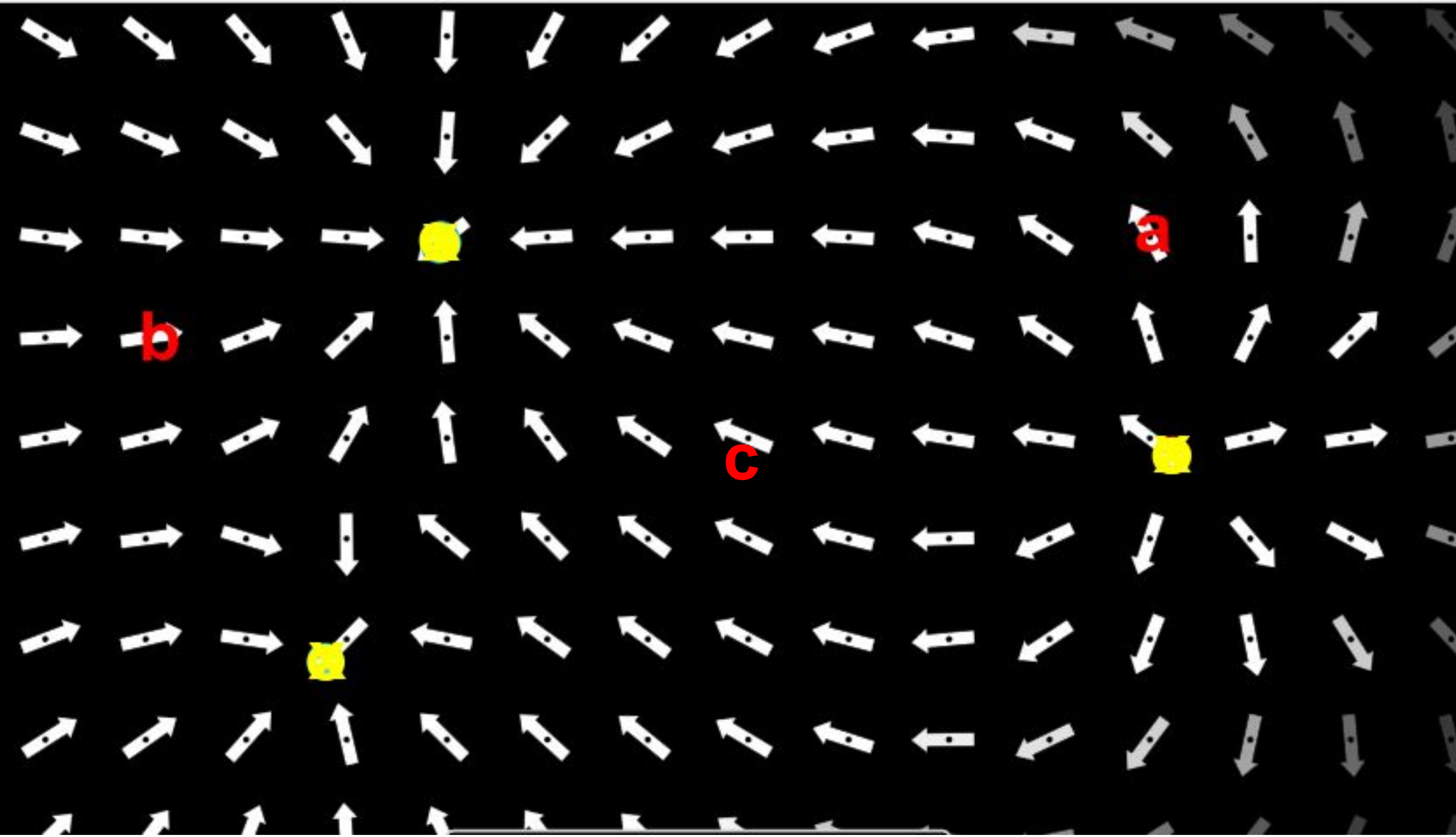


https://phet.colorado.edu/en/simulation/charges-and-fields

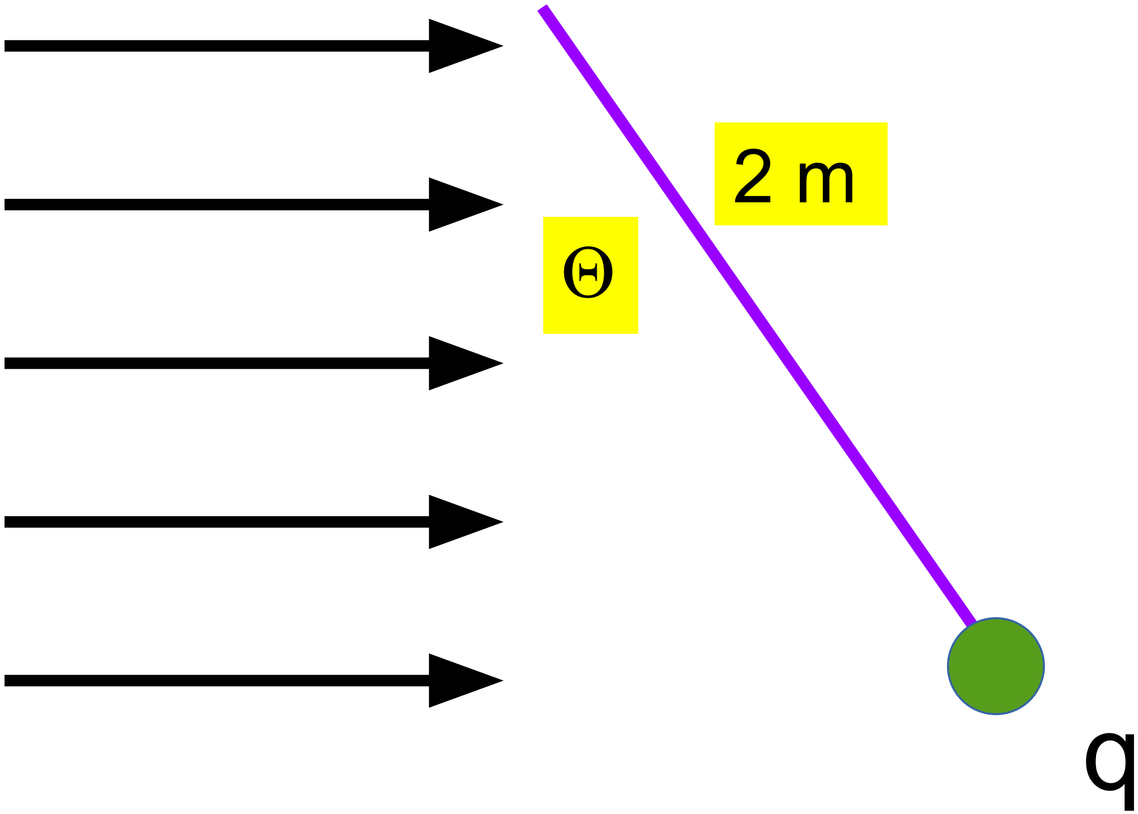
Draw approximate E vectors from 2C (blue) and -4C (purple) and add graphically (red dash)



Using the mountain/depression analogy, the PE of a +q charge follows:
A)PE(a)>PE(b)>PE(c); B) PE(a)<PE(b)<PE(c); C) PE(a)>PE(b)>PE(c); D) PE(c)>PE(b)>PE(a)
Check your answer by: I) identifying the signs of the source charges, and ii) make a rough estimate of ΣkQ/r, taking into account those signs

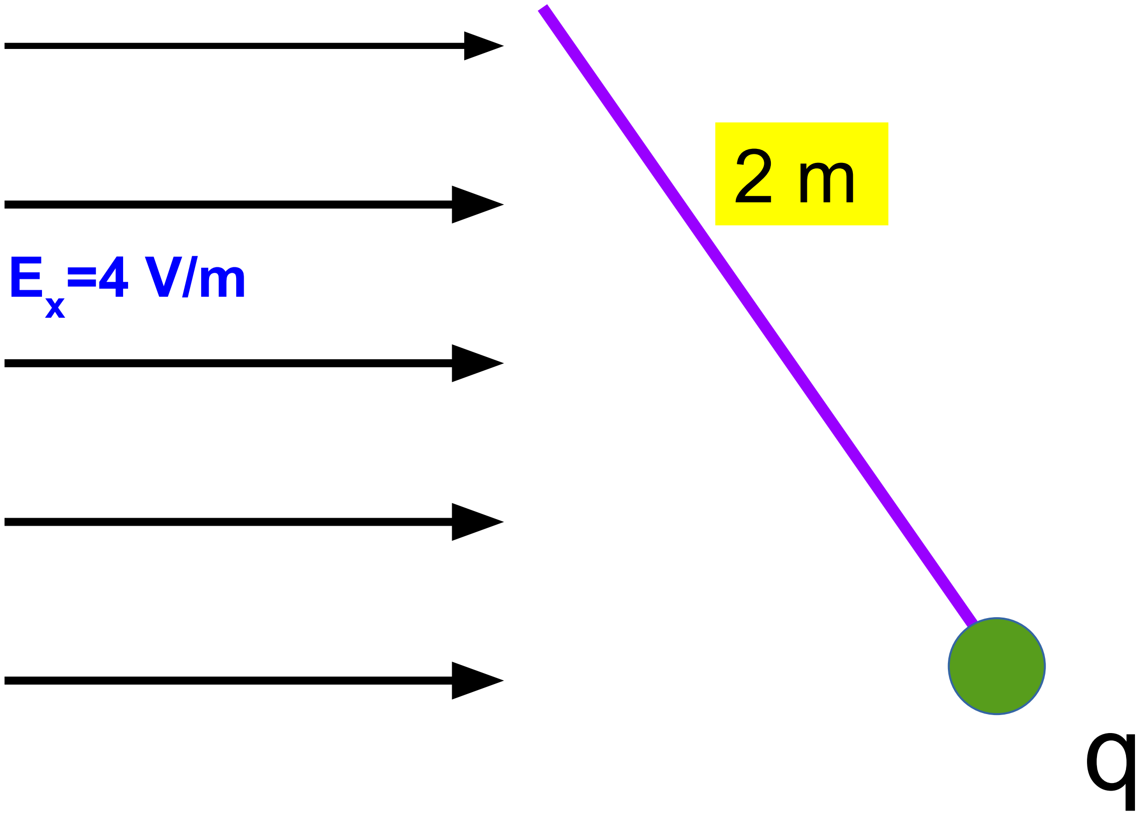


A 1.02 kg mass, with |q|=2 C, on a 2 m rope in a field with E_x=4 V/m makes an angle θ. The total # of forces acting on q, and the sign of q is:



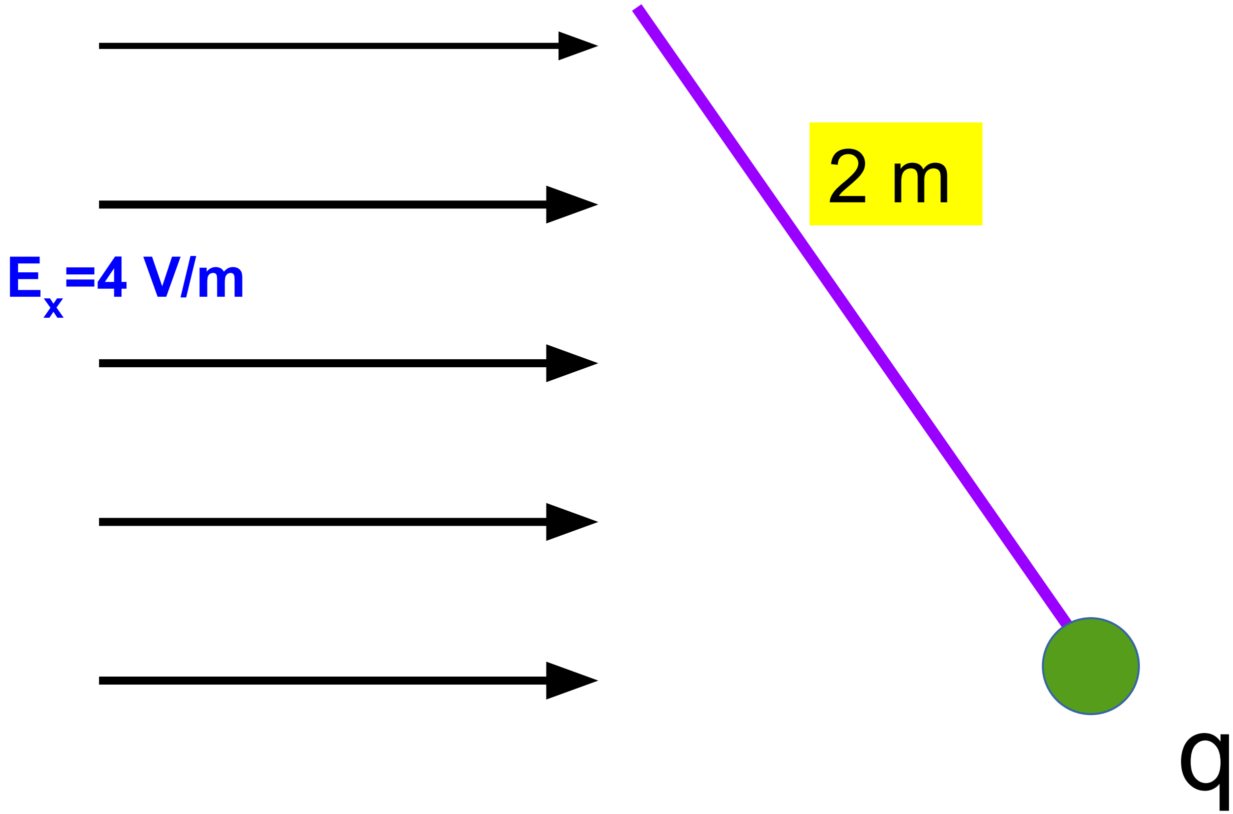
A) 1, +
B) 2, -
C) 3, +
D) 4, -
E) NOTA

The tension in the string is:



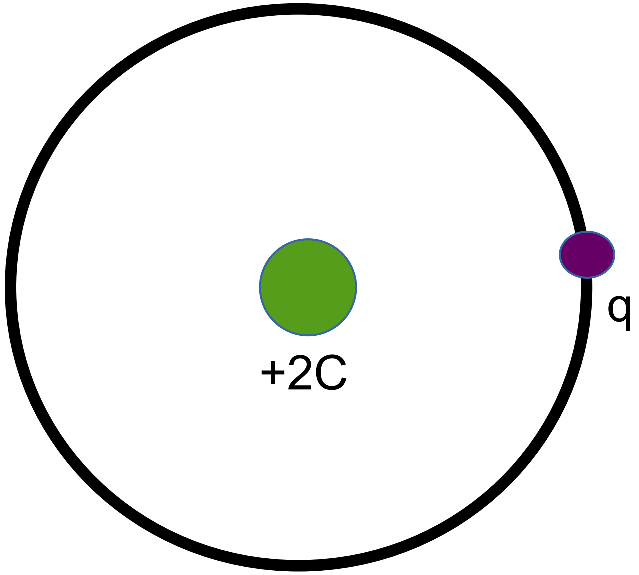
A) 8 N
B) 10 N
C) 12.8 N
D) 15 N
E) NOTA

For m=1.02 kg, the angle Θ is:



A) 38.6°
B) 51.3°
C) 45°
D) 30°
E) NOTA

Charge q, with mass 1 kg orbits (radius 10 m) around +2C source with v=100 m/s. The value of the charge q is:



A) -10^{-6} C

B) -5.55×10^{-6} C

C) -10^{-4} C

D) -2 C

Two identical electric charges, each with charge q and mass 4 kg, hang at the ends of two 2m ropes, which are separated by a total angle of 60°. q=

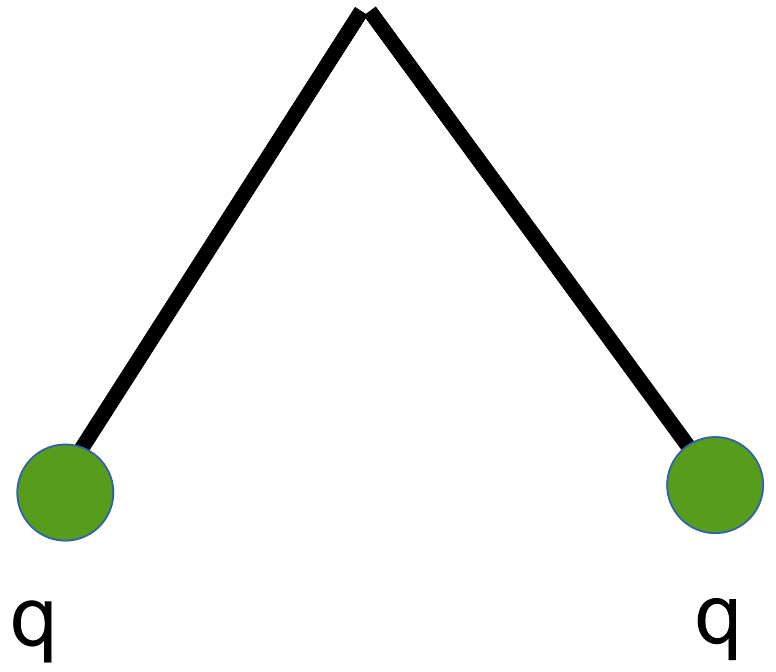
A) 6.4×10^{-5} C

B) 3.2×10^{-5} C

C) 1.0×10^{-4} C

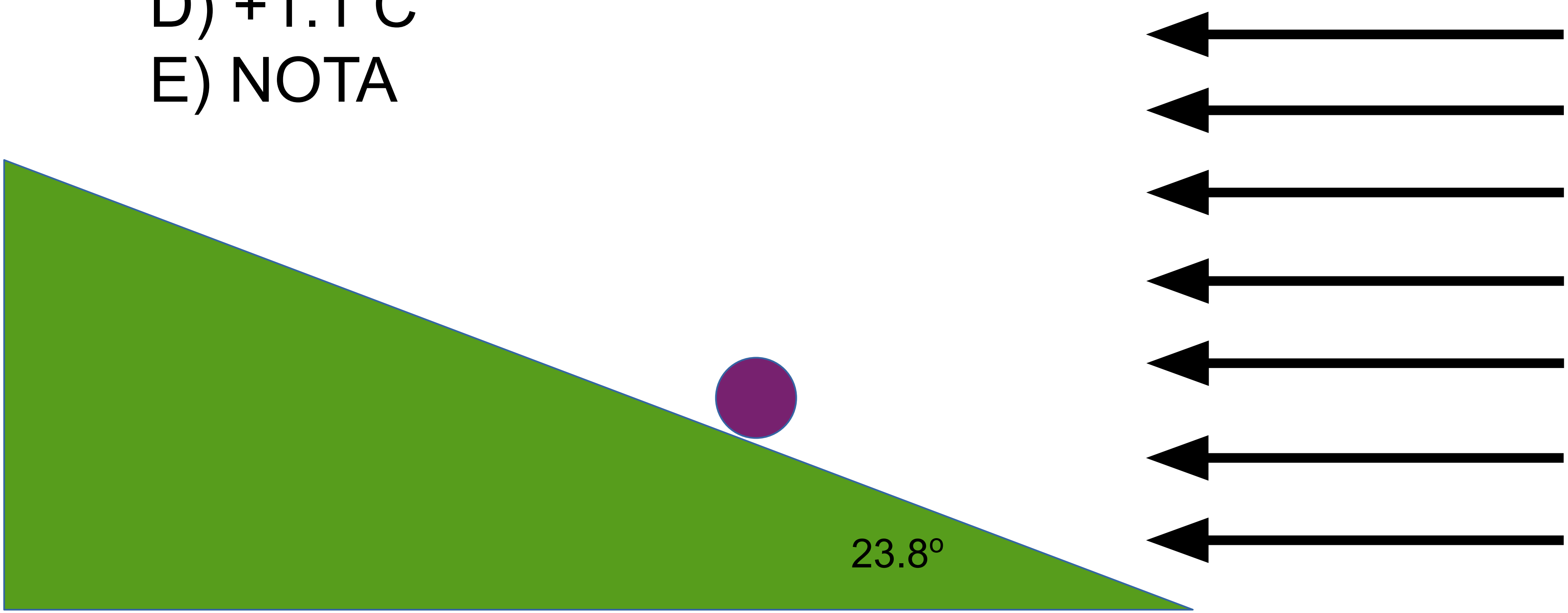
D) 9.33×10^{-5} C

E) NOTA



A charged 2.04 kg mass is stationary on a frictionless incline with angle 23.8° wrt. horizontal, in a field E_x=-4N/C; q=?

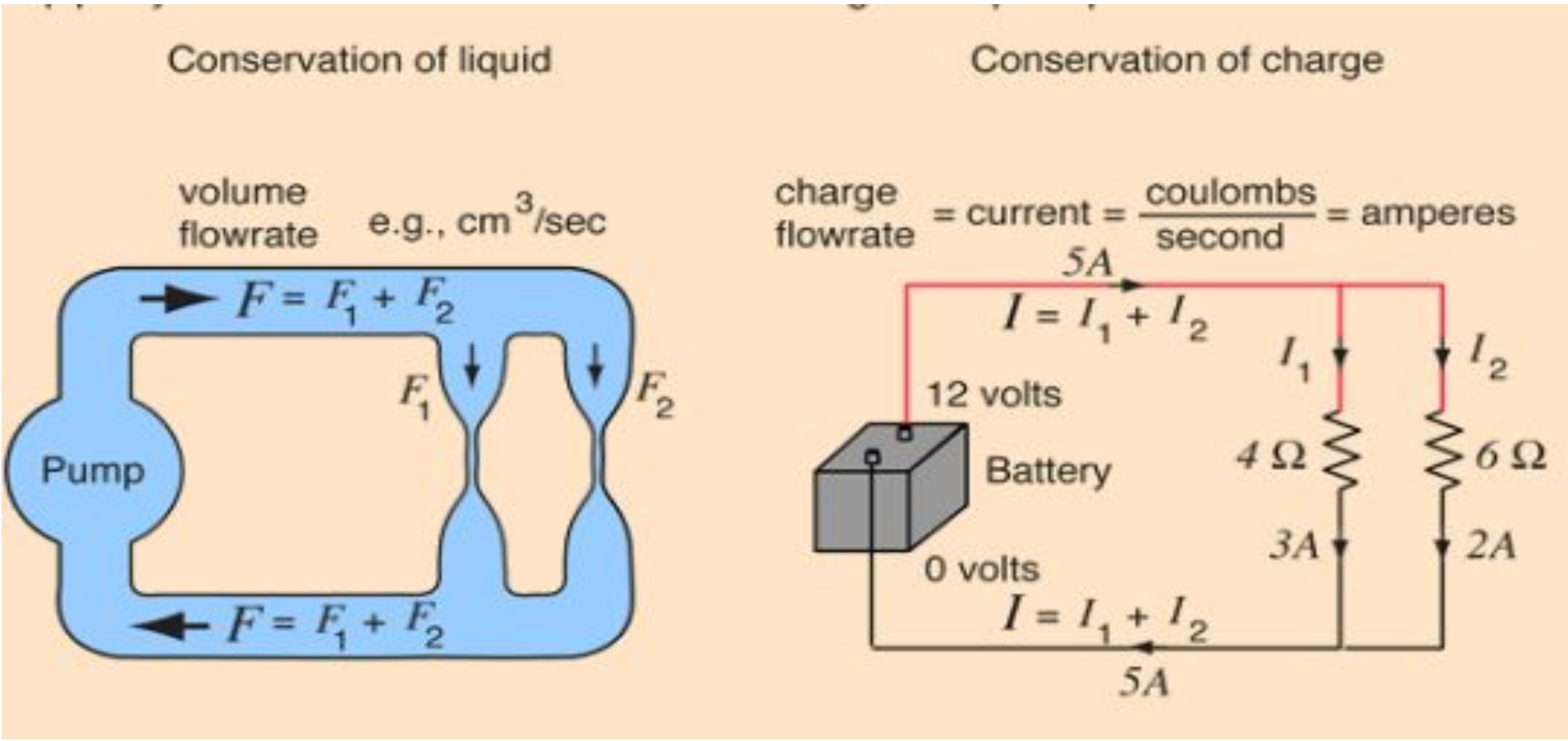
A) -2.2 C
B) -1.1 C
C) +2.2 C
D) +1.1 C
E) NOTA



Capacitance and Batteries.

For gravity, we can use gravitational potential energy as an energy source (hydroelectric, e.g.). The KE of masses stored at high PE is recovered when water flows over the Kaw river; water tower is another example.

A capacitor is an electrical "water tower", which stores charge. A battery is analogous to the water pump that gets water up to the top of the water tower. Principle: Series: sum of voltage drops through height h=voltage supplied; Parallel: all voltage drops same. When caps added in series, they must have the same charge and Sum(V)=V_{ext} =>add as inverses. Added in parallel, each cap has same V (add linearly). Charge Q=CV


Conservation of liquid
Conservation of charge
volume flowrate e.g., cm^3/sec
$F = F_1 + F_2$
F_1
F_2
Pump
$F = F_1 + F_2$
charge flowrate = current = $\frac{\text{coulombs}}{\text{second}}$ = amperes
5A
$I = I_1 + I_2$
I_1
I_2
12 volts
Battery
4 Ω
6 Ω
3A
2A
0 volts
$I = I_1 + I_2$
5A

Procedure for solving circuit problems:

1) Battery+capacitors/resistors:

Reduce circuit to battery+series C or R

2) Capacitors: Reduce circuit to equivalent series capacitors

3) Resistors: Determine I for equivalent series resistors

4) Trace voltage drops through circuit, then use Q=CV or I=V/R to determine Q or I for circuit elements

In the water analogy, a capacitor is most like a:

A) Water pump

B) Water tower

C) Plumbing pipe

D) Hydroelectric generator

Which of the following formulas would you expect to be correct for the total charge Q stored on a ppc with capacitance C attached to a battery of voltage V?

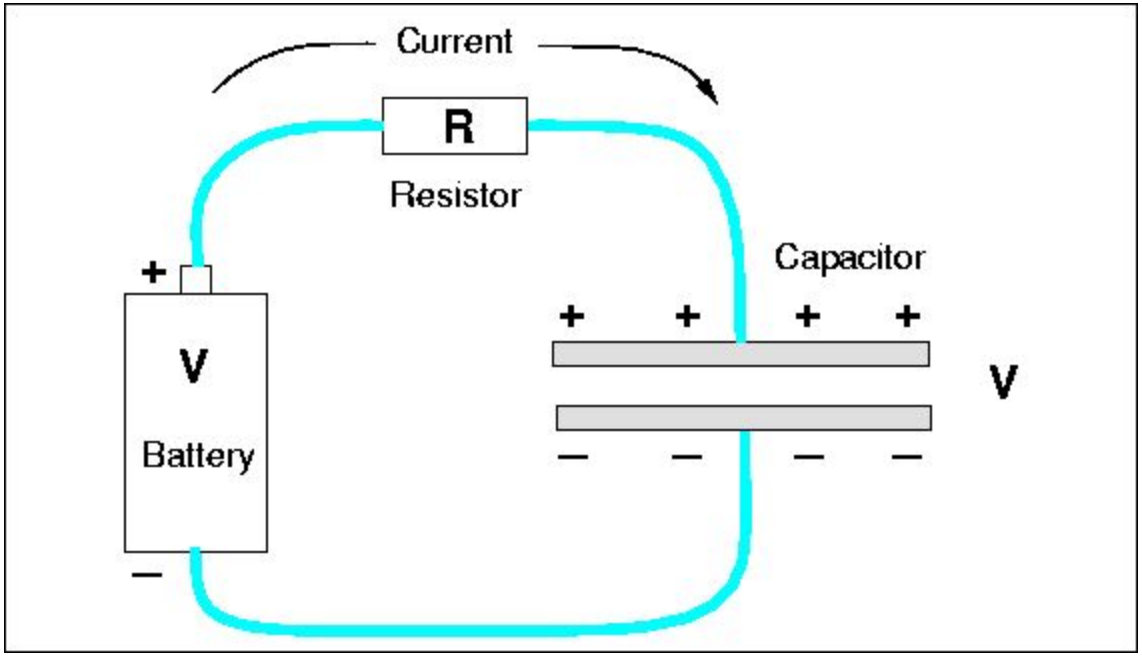
A) $Q=C/V$

B) $Q=V/C$

C) $Q=CV$

D) $Q=1/(CV)$

E) NOTA



A battery charges up a ppc (parallel plate capacitor). As time goes on, which of the following increase?

A) The rate at which charge flows onto the ppc
B) The total electrical energy stored in the ppc
C) The voltage across the ppc
D) Two of the above
E) All of the above

An 18V battery is attached to a $3F=C_1$ and $6F=C_2$ capacitor, in parallel. After charging up, the ppc's have charge

A) 12C, 6C

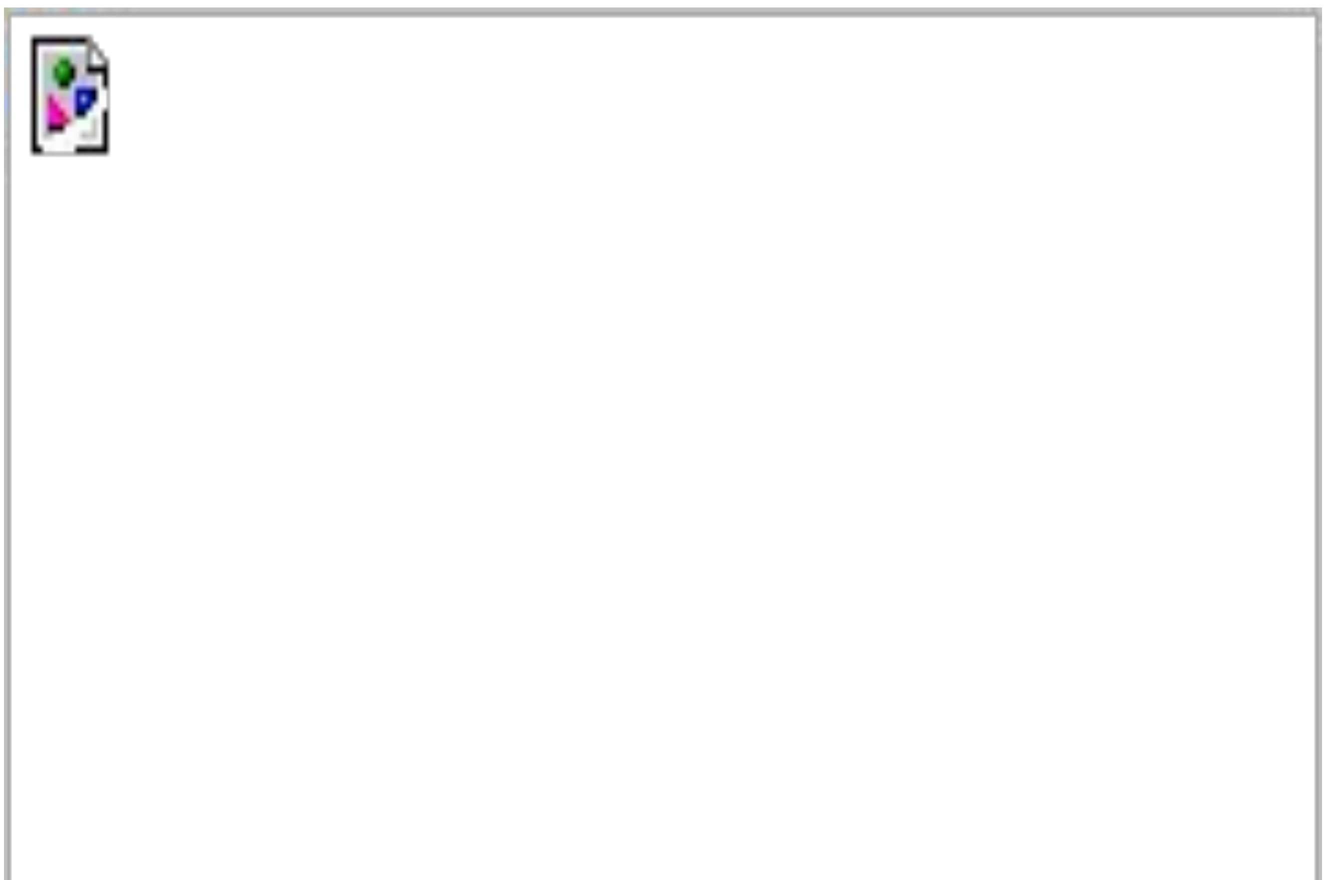
B) 54C, 108C

C) 36C, 36C

D) 12C, 24C

E) NOTA

An 18V battery is attached to a 3F (C_1) and 6F (C_2) capacitor, in series. After charging up, which would you expect to be true?



A) $Q_{-,1}=Q_{+,2}$

B) $V_1=V$

C) $V_2=V$

D) $V_1+V_2=V$

E) 2 or more are true

An 18V battery is attached to a 3F (C_1) and 6F (C_2) capacitor, in series. After charging up, the charge on the plates of the ppc's is (verify using Kirchoff's conservation of Voltage)

A) 6C

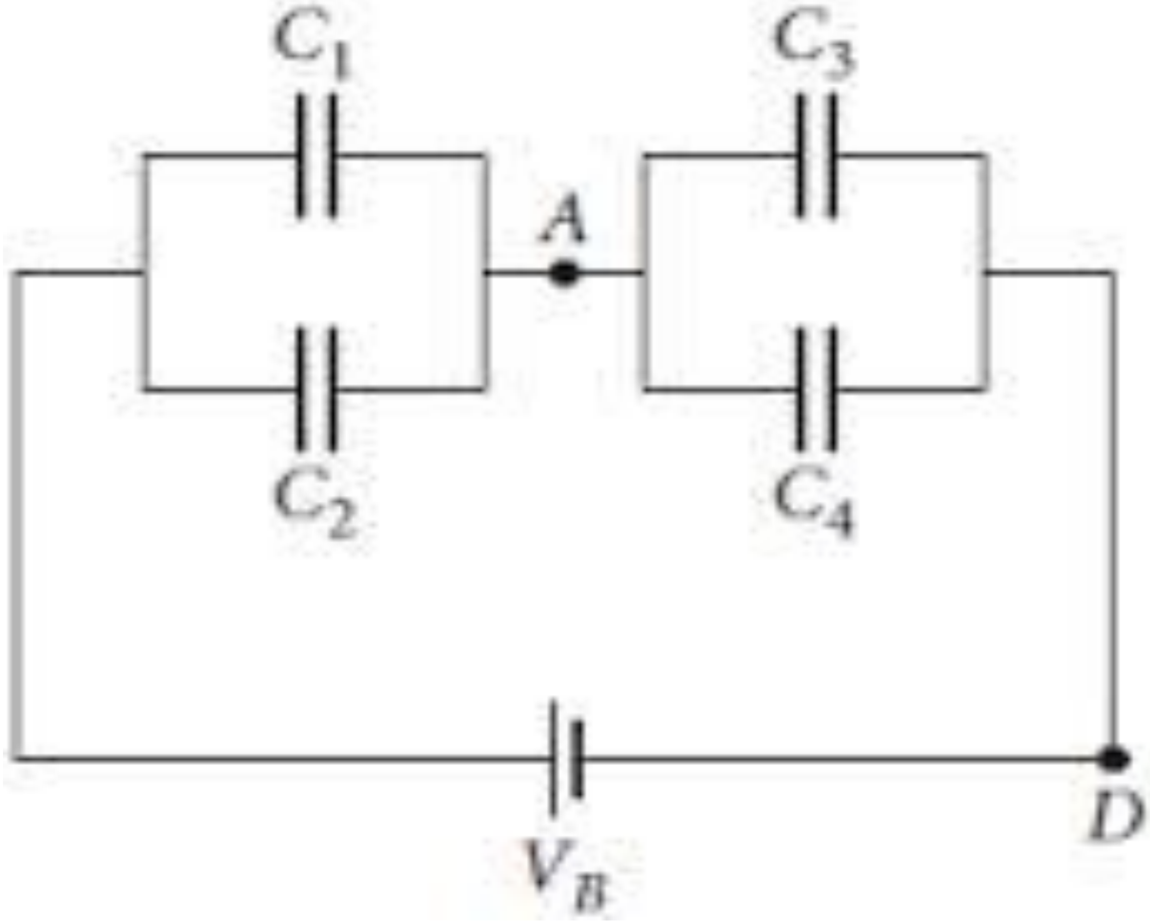
B) 36C

C) 0.111C

D) 9C

E) NOTA

In the circuit below, V_B=6 V, C_1 =2F, C_2=4F, C_3=C_4=6 F; after fully charging up, the charge on capacitor C_1 and C_3 are, respectively:



A) 12C, 12C
B) 16C, 8C
C) 8C, 12C
D) 4C, 4C
E) NOTA

In the same circuit, the voltage at A is:

A) 6V

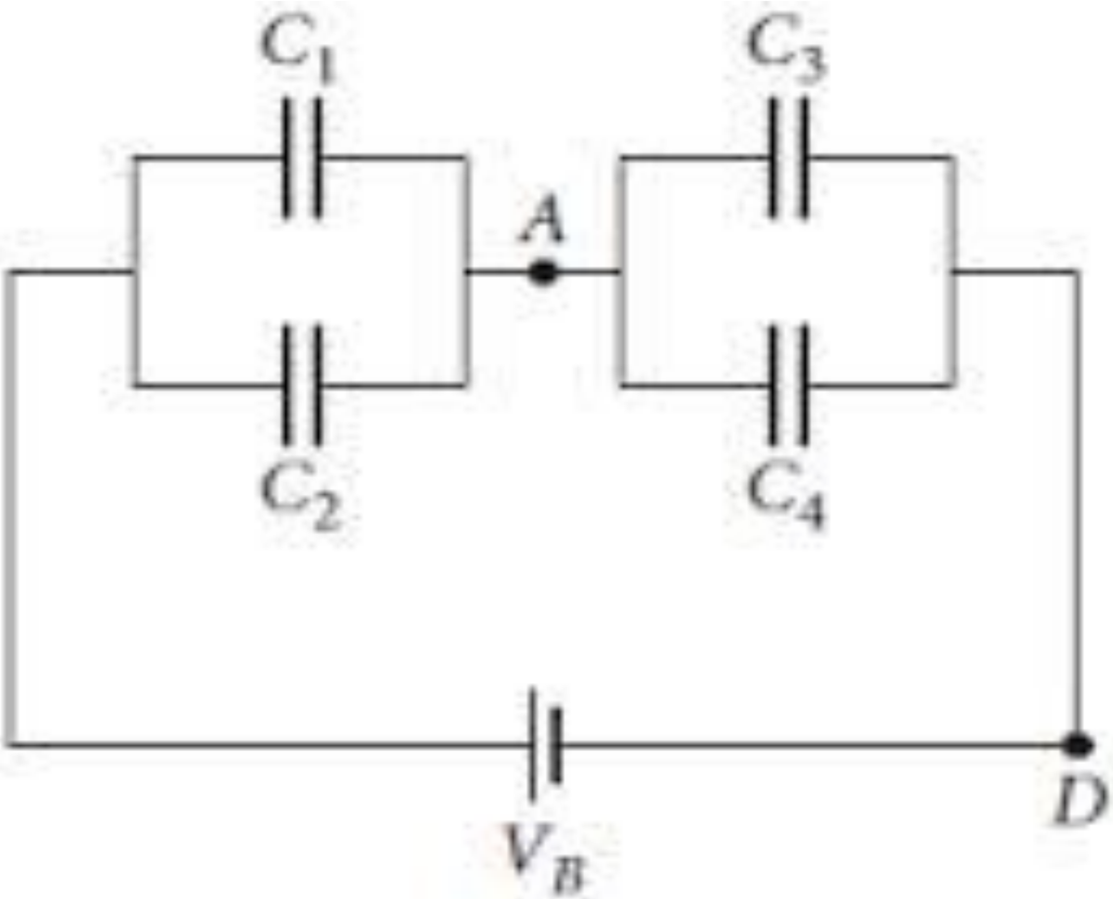
B) 4V

C) 2V

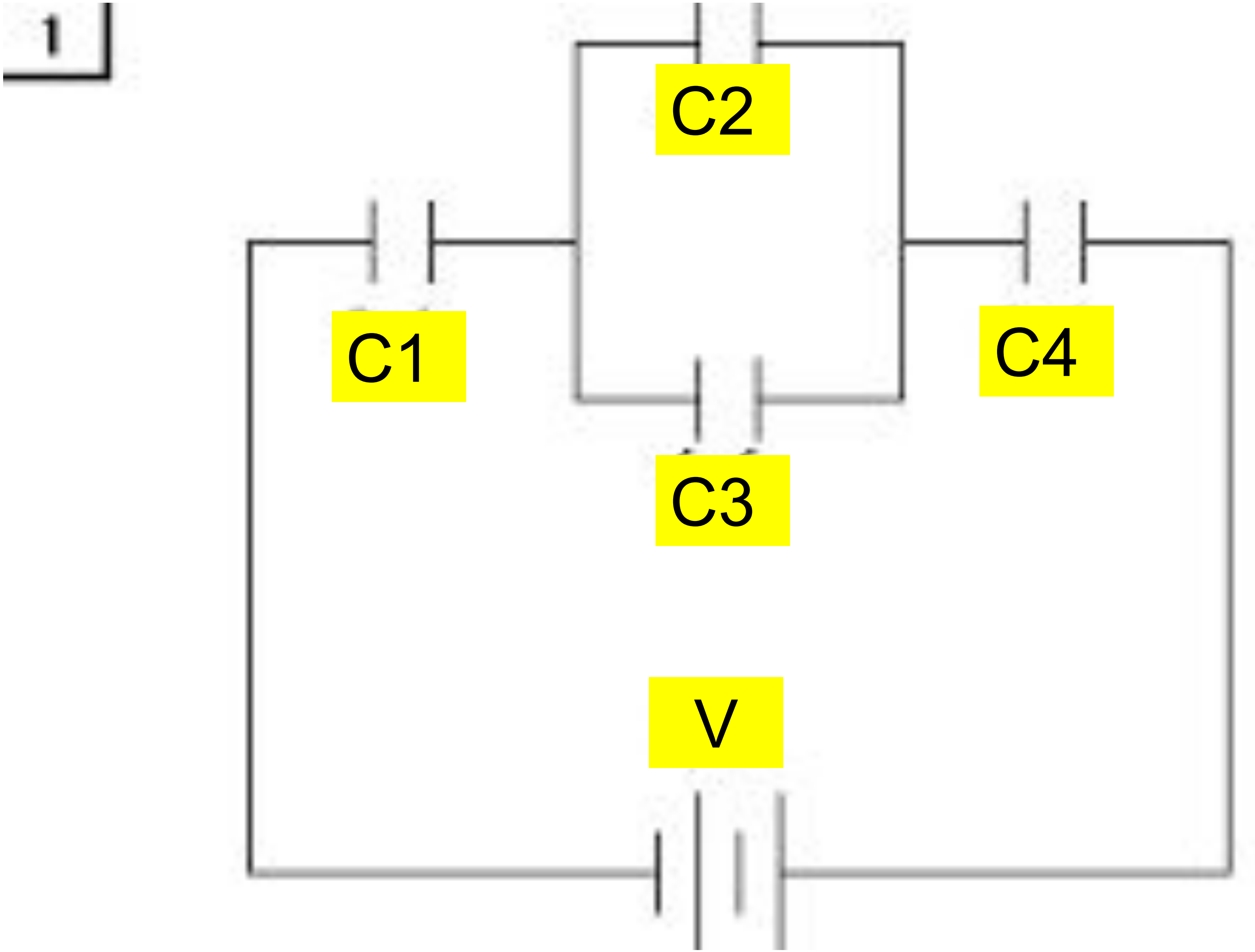
D) 0V

E) NOTA

Suppose V_B was reversed?



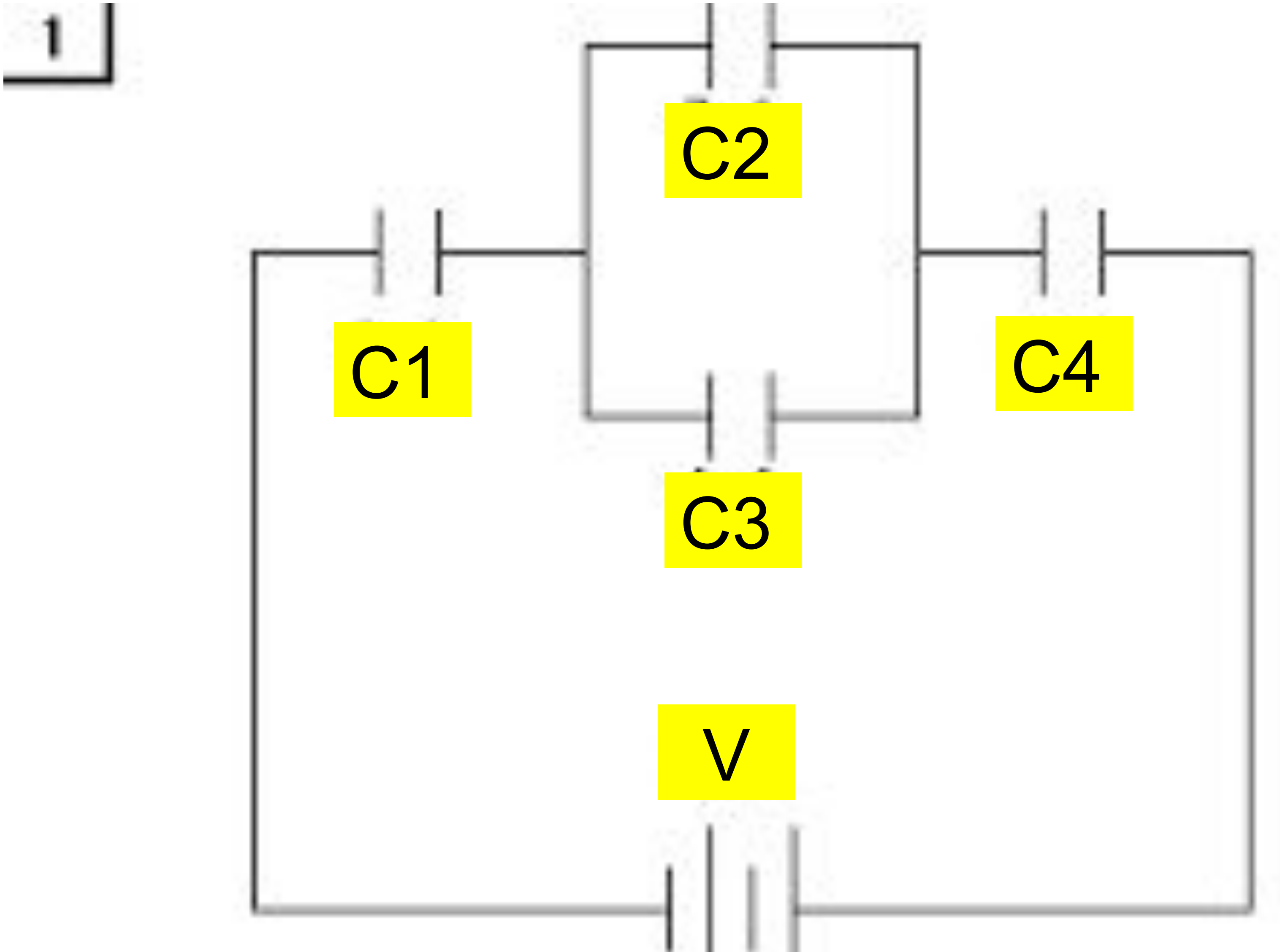
If V=12V, C1=2F, C2=4F, C3=2F, C4=3F. The charge on Q_4=



A) 2C
B) 6C
C) 12C
D) 18C
E) NOTA

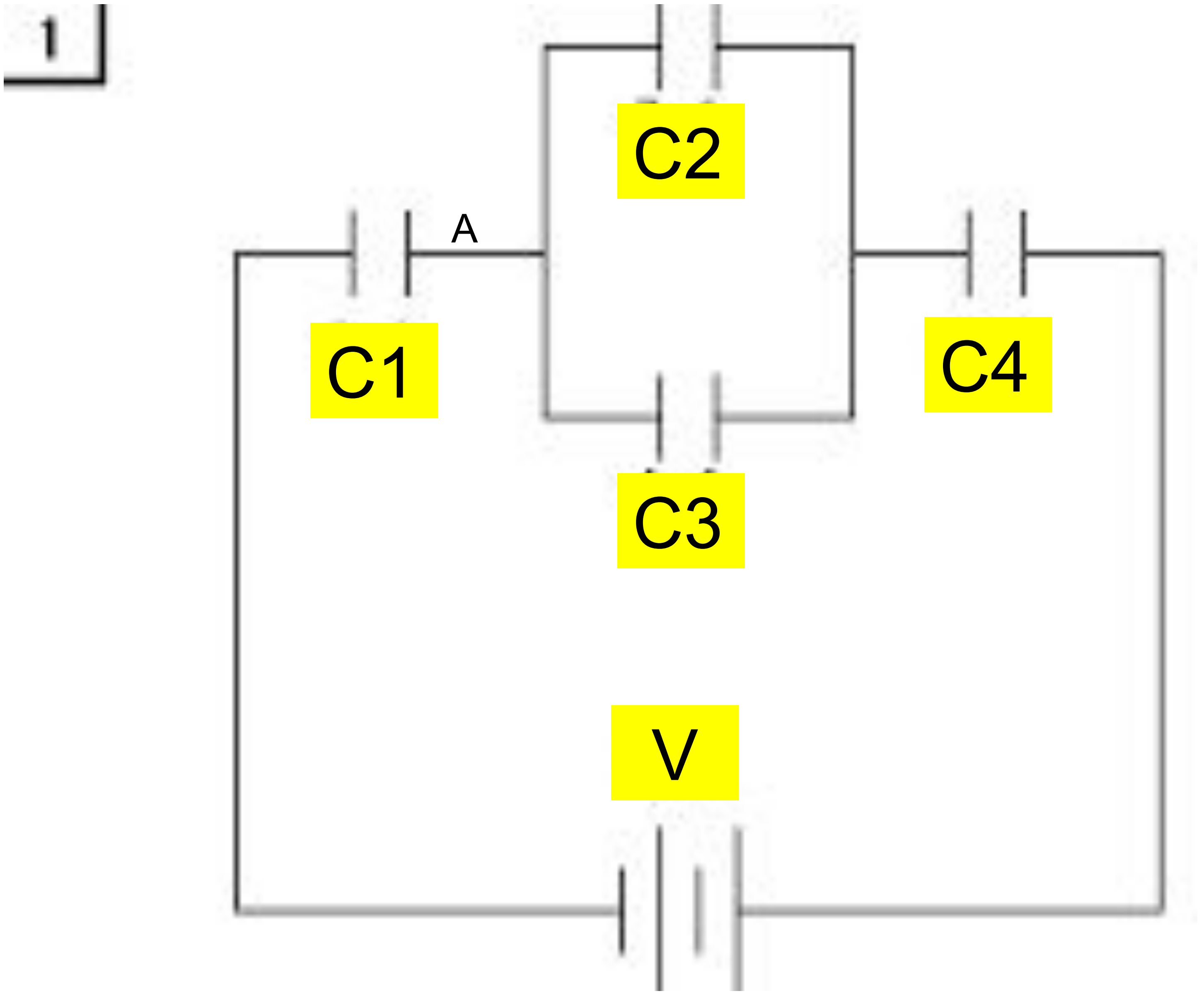
In the circuit, V=12V, C1=2F, C2=4F, C3=2F, C4=3F. The energy stored on C2 is:

A) 2J
B) 6J
C) 12J
D) 8J
E) NOTA



In the circuit, V=12V, C1=2F, C2=4F, C3=2F, C4=3F. The voltage at point A is (check by working both ways through the circuit!):

A) 2V
B) 6V
C) 12V
D) 8V
E) NOTA

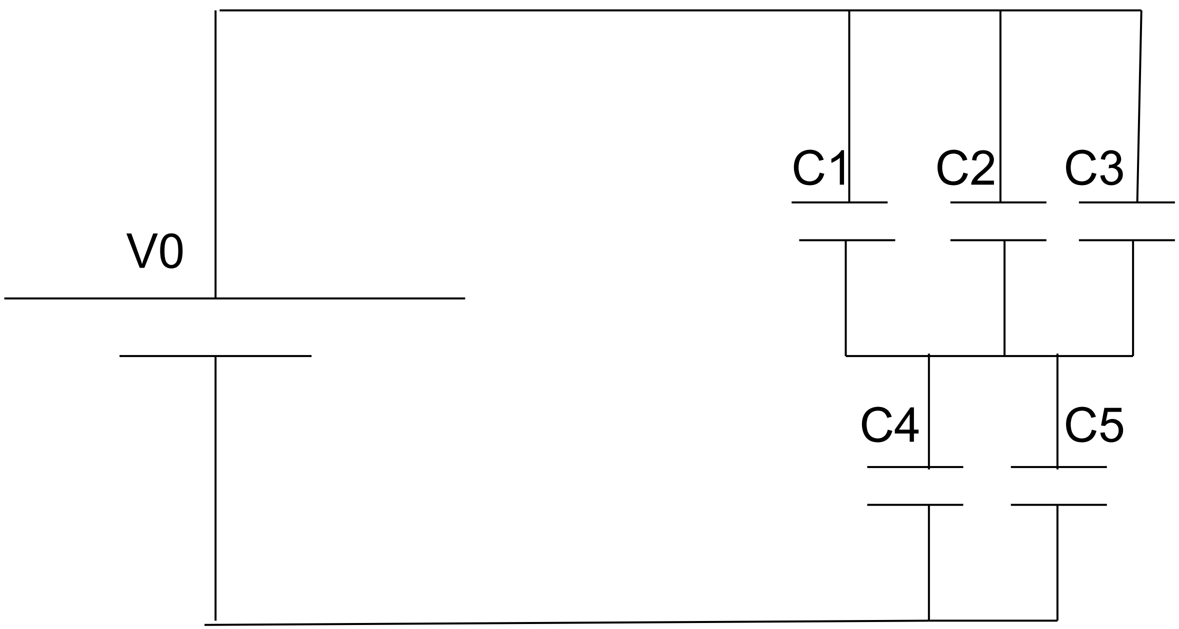


Capacitance and Batteries

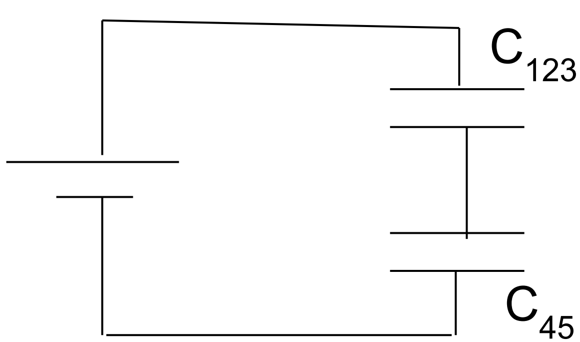
Given one battery and five capacitors. Assign unique values to the 5 capacitors and the one battery. Determine the charge on each capacitor, when fully charged up, the total charge from the battery, and the total energy required to charge up the 5 capacitors. Verify your results using Kirchoff's Laws for one `closed loop'.

Given V0=24V, C1=1F, C2=2F, C3=3F, C4=8F and C5=4F, find charges on all Caps. Verify your answers using Kirchoff's principle.

Soln: 1) Find equivalent circuit: C_{123}=1F+2F+3F=6F; C_{45}=12F, so circuit is equivalent to a 24V source with a 6F and 12F Capacitor in series:

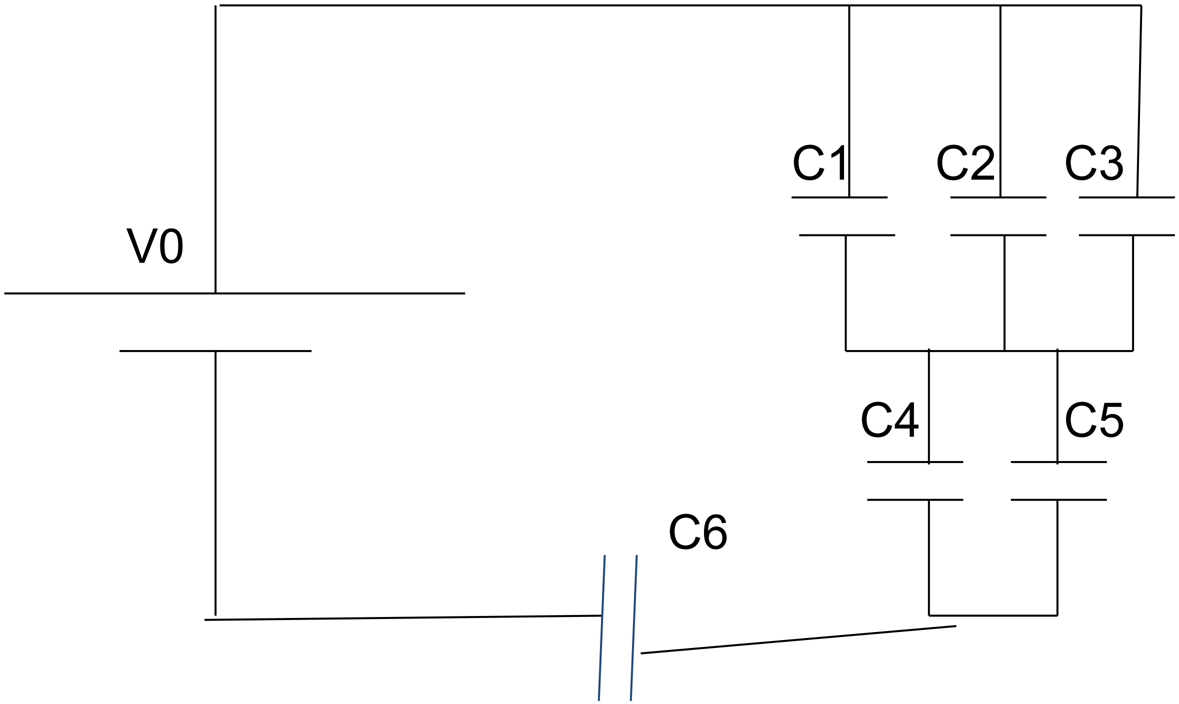


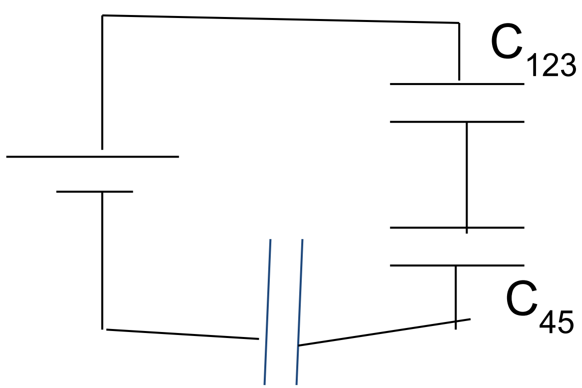
Alternately: 1. reduce circuit to series combination, then 2. use Kirchoff with Q same on series combiinations & solve for Q:
24V=Q/6+Q/12 gives Q=96 C, so V123=16V, so Q1=16C, Q2=32C, Q3=48C, V45=8V, Q4=64C, Q5=32C



2) Find equivalent resistance of series combinations:
$1/C_{12345}=1/C_{123}+1/C_{45} \Rightarrow C_{12345}=4F$
3) Solve for charge Q on C_{12345}=96C. This also is the charge on each of the series combinations, so 96C=Q_{123}=Q_{45}
4) Solve for voltage drops through caps: V_{123}=96C/6F=16V; V_{45}=8V (check that sums to V0!)
5) Now solve for individual charges on individual caps:
Q_1=16V*1F=16C; Q2=32C; Q3=48C
Q4=8V*8F=64C; Q5=8V*4F=32C

Given V0=24V, C1=1F, C2=2F, C3=3F, C4=8F, C5=4F and C6=4F, find charges on all Caps. Verify your answers using Kirchoff's principle.





Equivalent Circuit Solution

Applicable to circuits consisting of one battery and some number of R or C

1) Add parallel caps/resistors from inside→out and reduce circuit to battery + series capacitors

2) Use $V_{Battery}=Q/C_{1,series} + Q/C_{2,series} + Q/C_{3,series}\ldots$ to find charge on each equivalent series capacitor.

3) This now gives the voltage across each equivalent series capacitor, which can be used to find the charge on each individual capacitor.

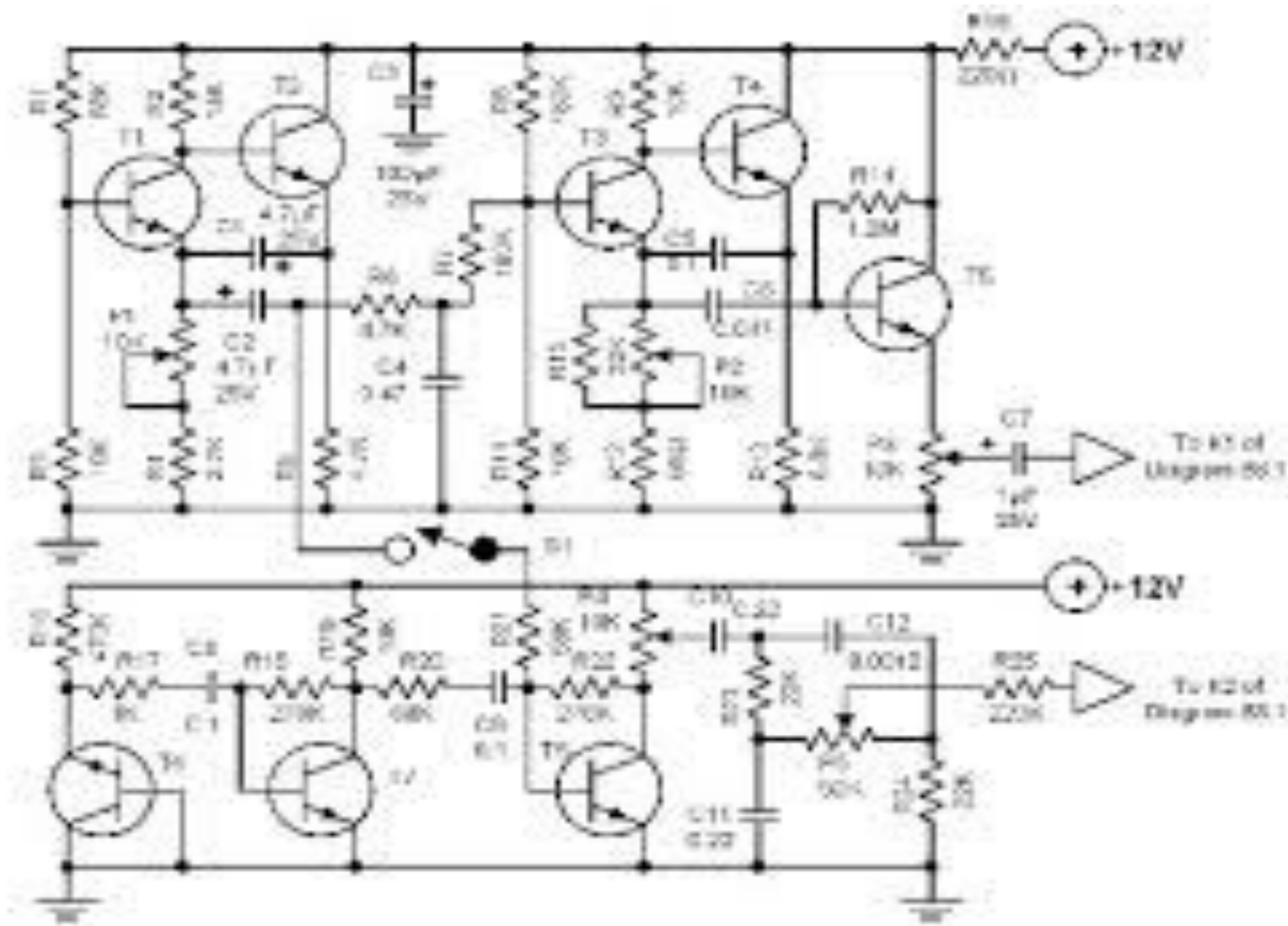
4) PE in each capacitor is given by $Q^2/2C$

Checks:

a) Kirchoff's rules for each closed loop

b) Q should equal the same value of Q when circuit is reduced to one equivalent capacitor.

In the circuit below, what is the voltage difference between points A and B?



Relating charge flow to current

[qv]: Coulombs-meters/second
[IL]: (Coulombs/sec) x meters

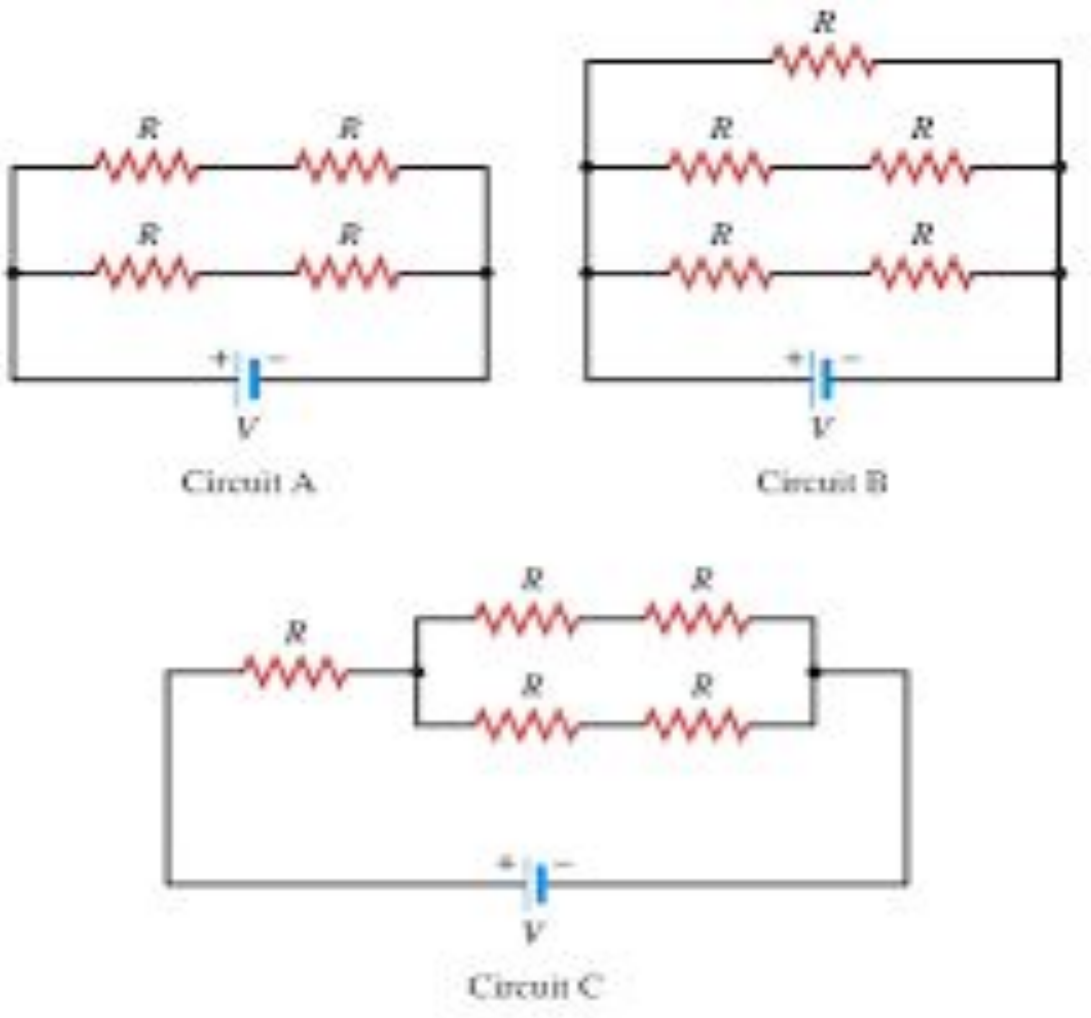
so [I]:[qv/L], where L is distance traveled by charge in one second.

Resistors: In the water tower analogy – pump=battery, tower=capacitor, voltage across capacitor is the water pressure. How is the water conveyed to the ground? Can have multiple tubes/pipes connecting tower, either in parallel or series… parallel => more paths for water to flow through, so reduced resistance (or think about blowing through straws, either in series or parallel)

Kirchoff's Laws: after assigning current flow directions:

1. ΣV, through closed loop=0
2. ΣI at a junction=0, with currents flowing into junction positive and currents flowing out negative.

I_{tot} is largest for which circuit? V=12V; R=12 Ω



A)

B)

C)

D) all=

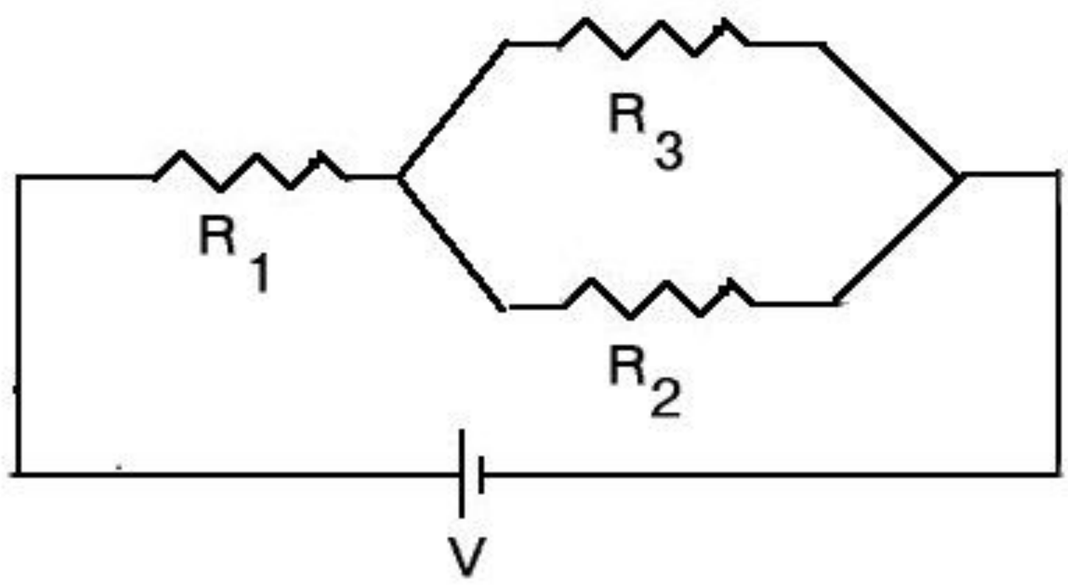
Given V=12 V; for which values of R_1, R_2 and R_3 is the total current from the battery largest?

A) 4Ω, 5Ω, 6Ω

B) 6Ω, 4Ω, 4Ω

C) 3Ω, 6Ω, 6Ω

D) Same for all cases



In which of the 3 cases above is the voltage drop across R1 largest?

Given $V=12$ V; $4\Omega=R_1$, $3\Omega=R_2$ and $6\Omega=R_3$, the total current from the battery is:

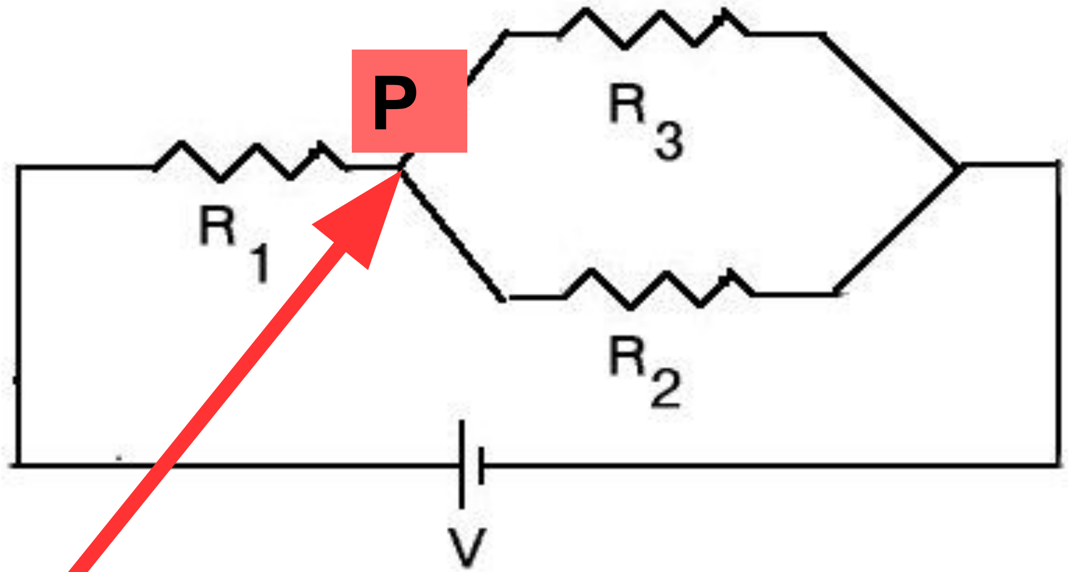
A) 12/13 A

B) 13/12 A

C) 6A

D) 2A

E) NOTA



The voltage at P is

A) 12V, B) 8V C) 4V, D) 0V E) NOTA

Given V=12 V; 4Ω=R_1, 3Ω=R_2 and 6Ω=R_3, the total amount of power dissipated as heat in the 3Ω and 6Ω resistors is, respectively:

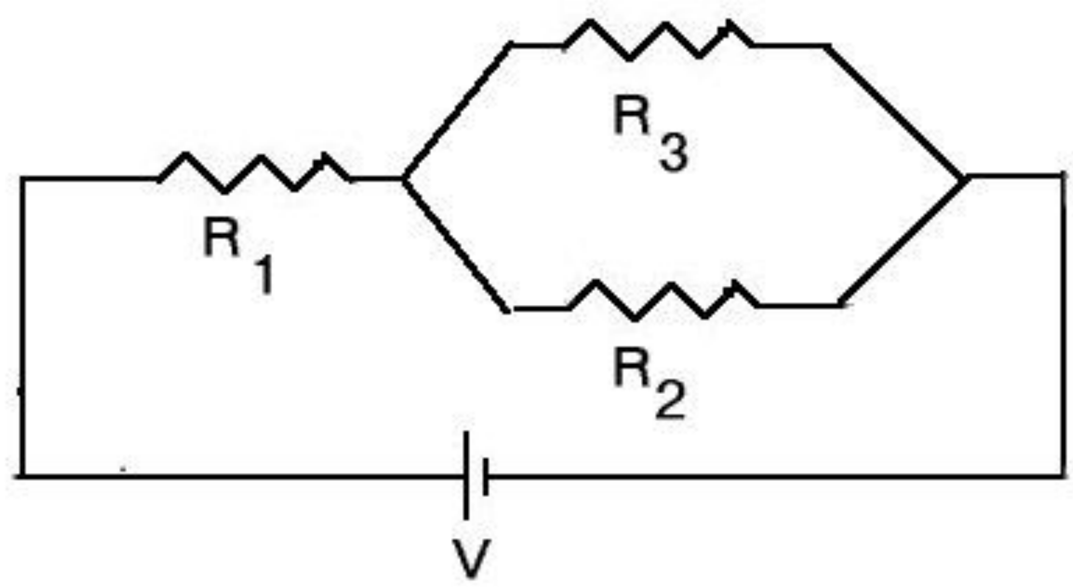
A) 5.33 W, 2.66W

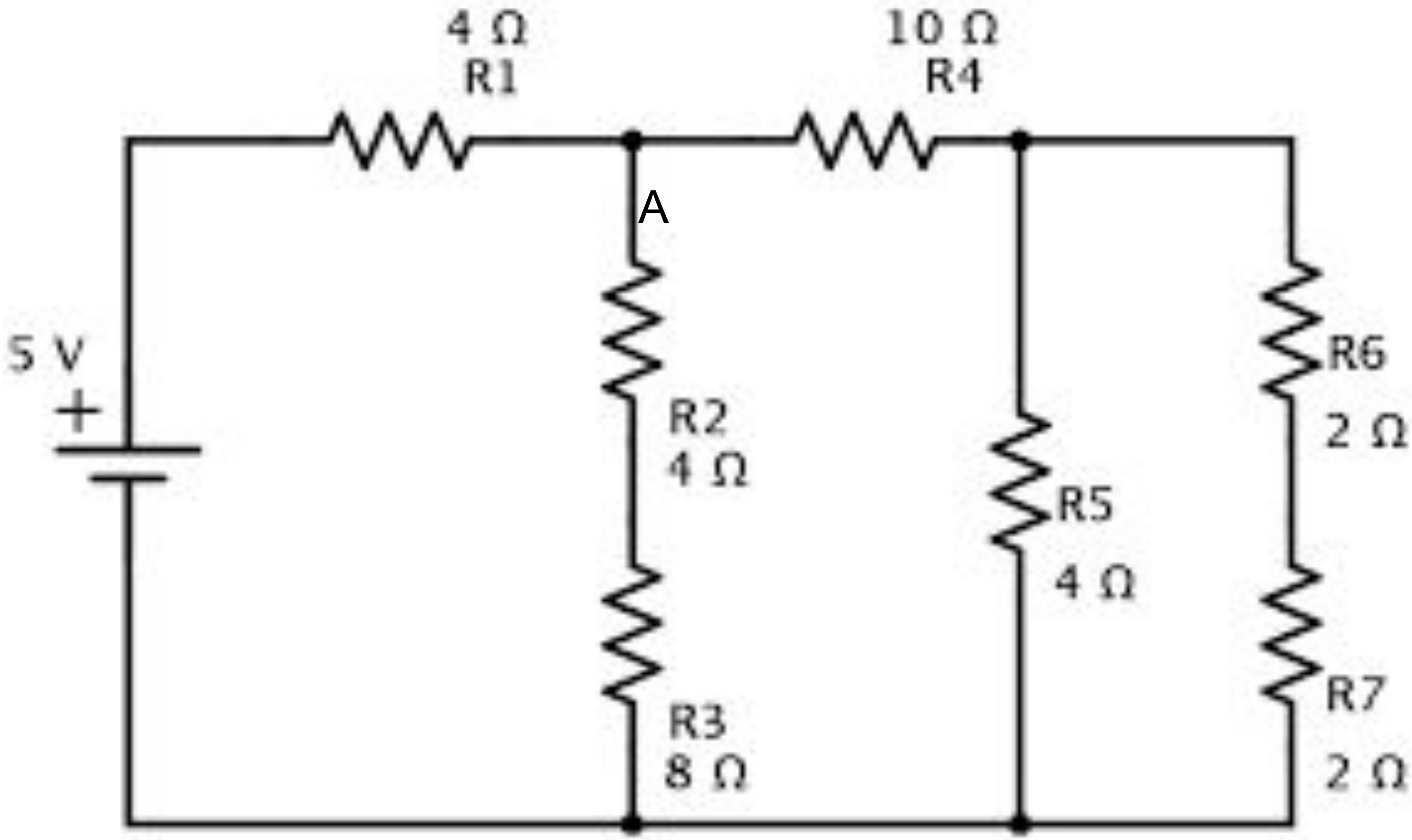
B) 2.66W, 5.33W

C) 2.66W, 2.66W

D) 5.33W, 5.33W

E) NOTA





A) 0.5 A

B) 0.25 A

C) 0.125 A

D) 2 A

E) NOTA

The current I_{tot} is:

<u>Remember to check your results for currents by verifying that the total voltage drop through a closed loop is equal to the voltage supplied by the battery!</u>

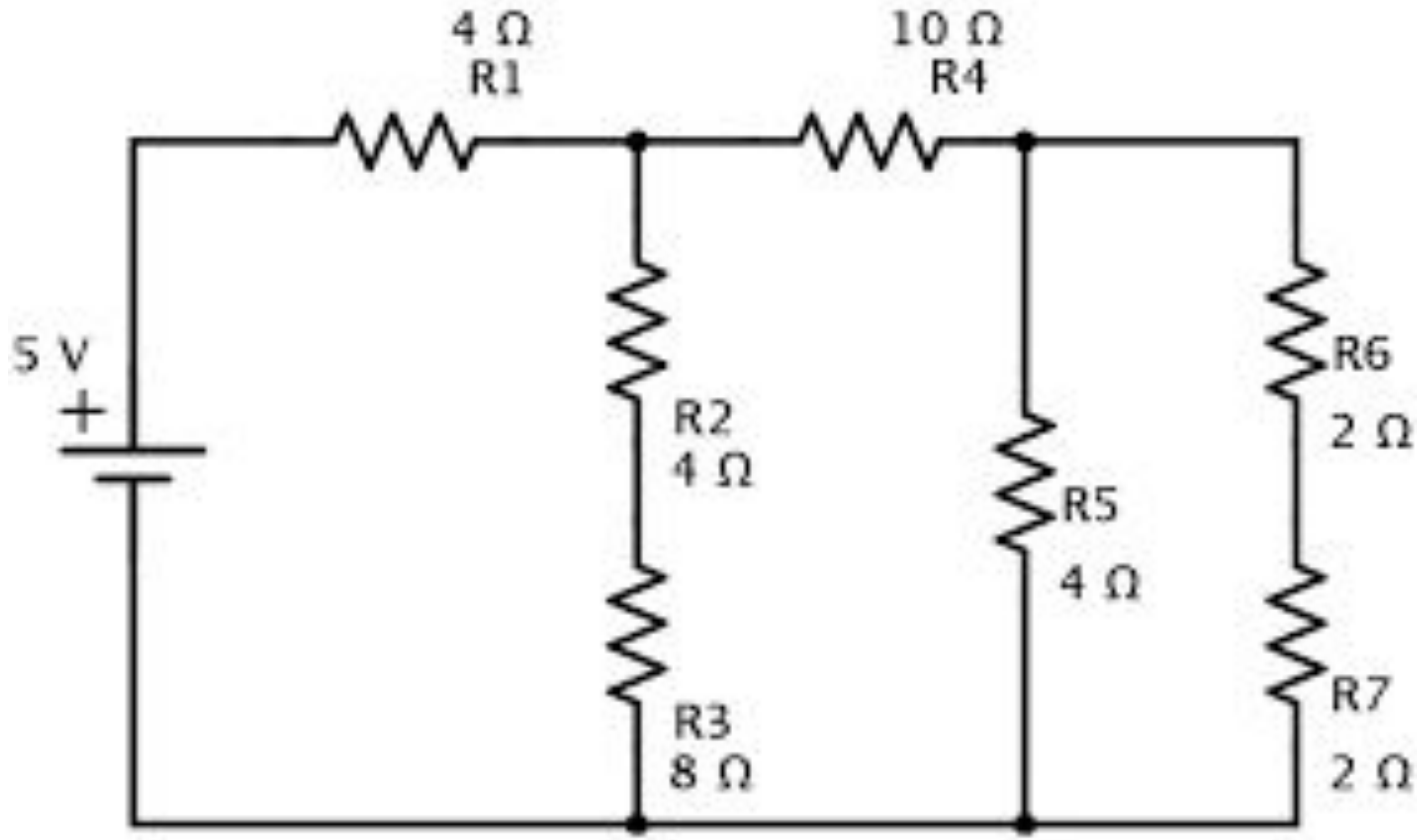
A) 5 V

B) 2.5 V

C) 3 V

D) 2 V

E) NOTA



The voltage drop across R_{23} is:

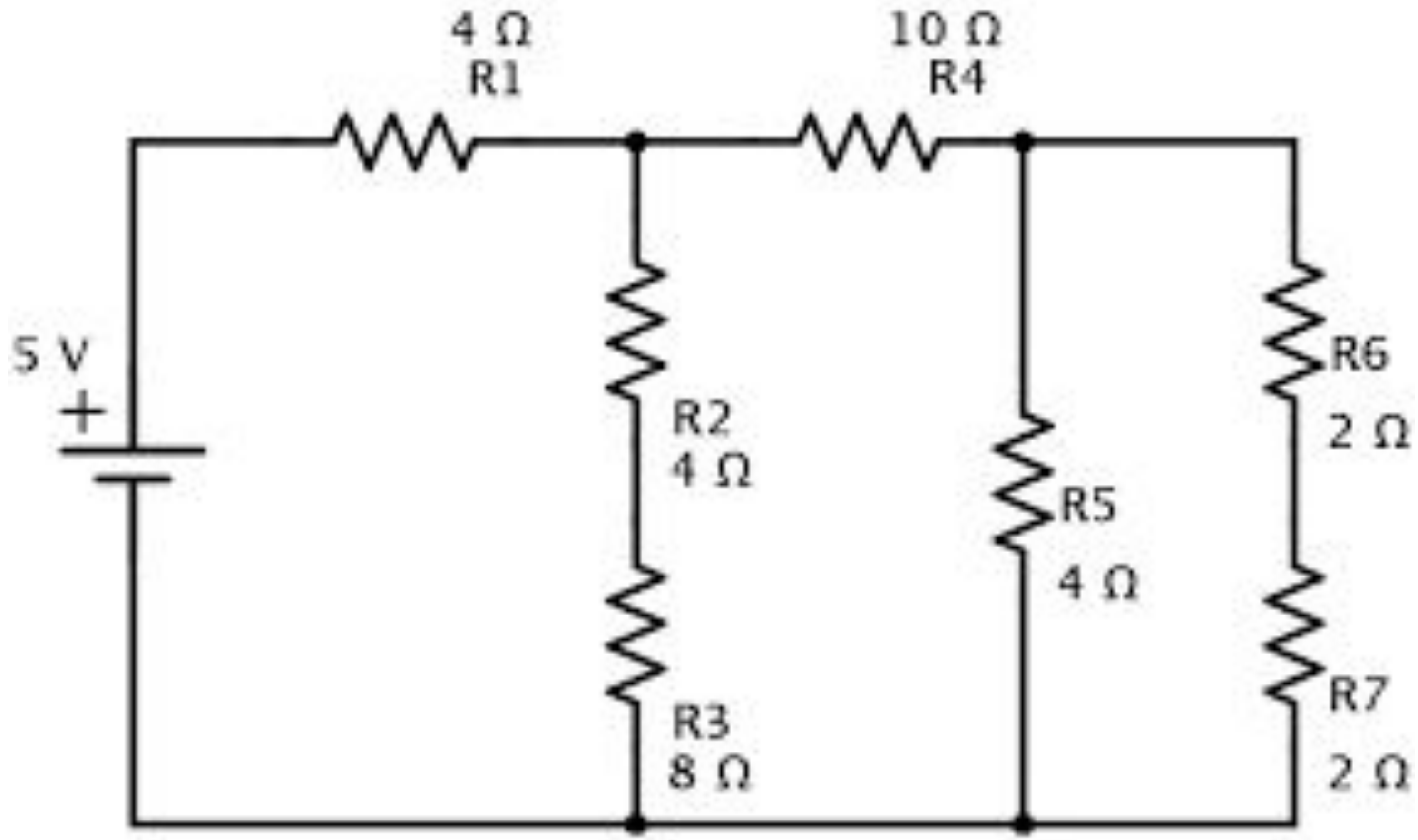
A) 5V

B) 0.25 V

C) 0.125 V

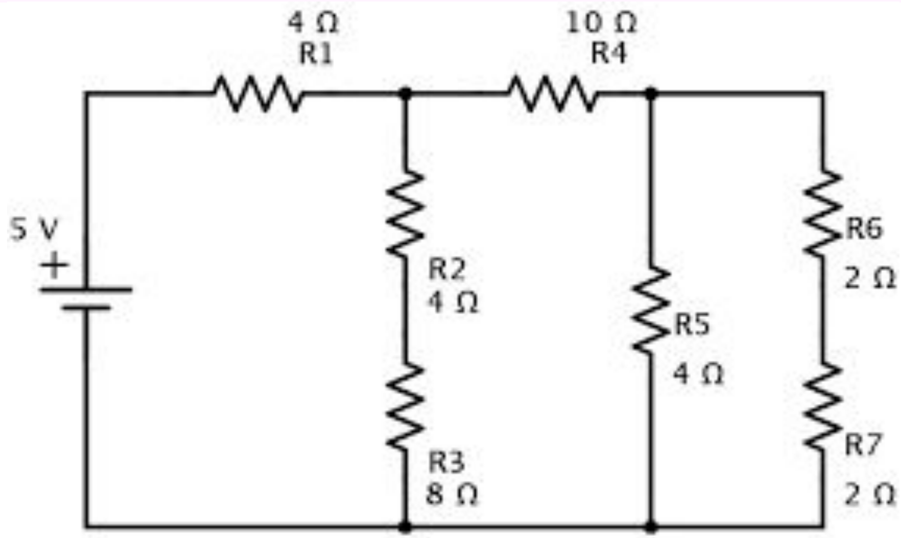
D) 2 V

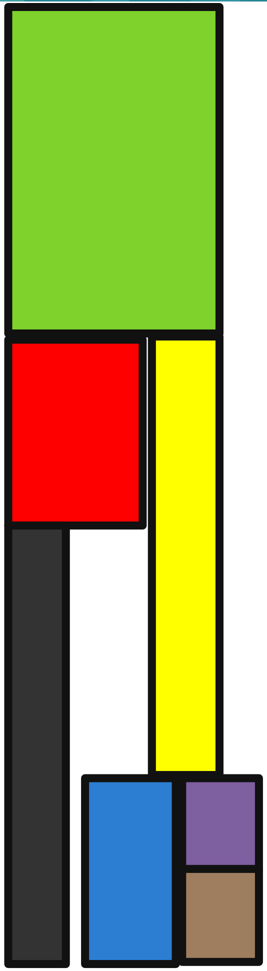
E) NOTA



The voltage drop across R6 is:

What color are `R2’ and `R5’, respectively?





A) Black, yellow

B) Yellow, black

C) Red, blue

D) Green, yellow

E) NOTA

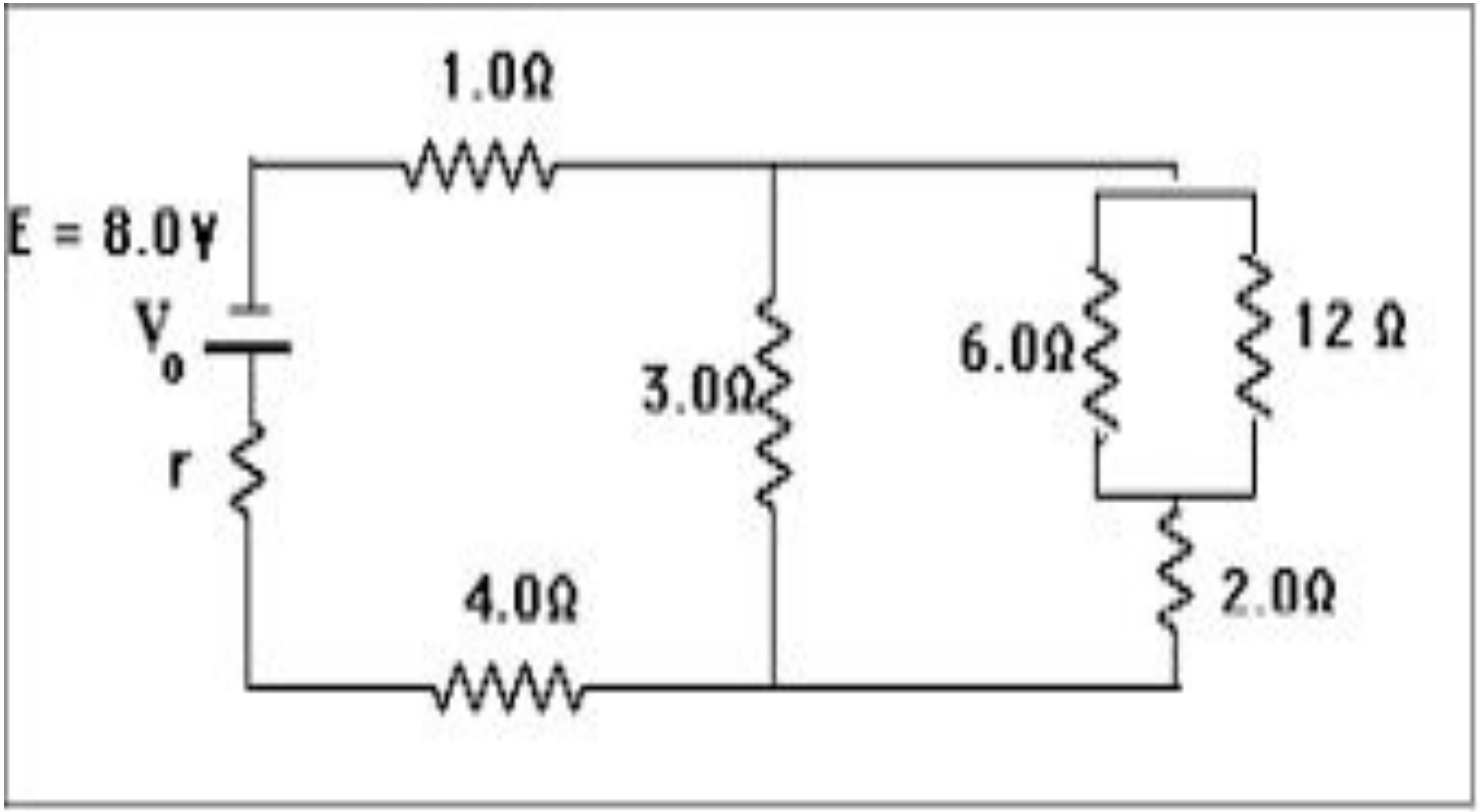
A) 1V

B) 2V

C) 2/3 V

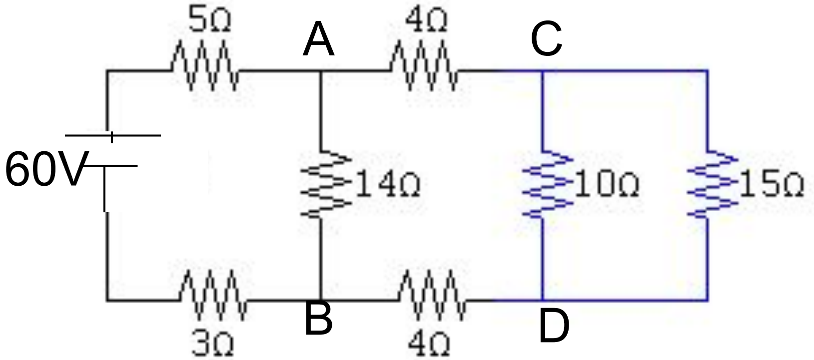
D) 4/3 V

E) NOTA



If r=1Ω, ΔV_{AB} across the 3Ω resistor=

<u>Remember to check your results for currents by verifying that the total voltage drop through a closed loop is equal to the voltage supplied by the battery!</u>



R_1=5Ω; R_2=3Ω; R_3=14Ω; R_4=4Ω; R_5=4Ω; R_6=10Ω; R_7=15Ω.
$R_6||R_7$=>R_{67}=6Ω; R_4, R_5, R_{67} all series=>R_{4567}=14Ω; in || w/ R_3=>R_{34567}=7Ω; R_{tot}=15Ω
=>I_{tot}=60V/15Ω=4A

Now determine currents and voltages through all individual resistors:

V_1=20V; V_2=12V, so V(A)=60V-20V=40V; V(B)=0V+12V=12V=>V_3=40V-12V=28V
=>I_3=28V/14Ω=2A.

If 4A flows into pt. A (and also out of pt. B), then current flowing A→C=4A-2A=2A=I_4=I_5
So V(C)=40V-2A*4Ω=32V; V(D)=12V+8V=20V, so V_6=32V-20V=12V=V_7 (since ||), so I_6=1.2A; I_7=0.8 A (check that I_6+I_7=2.0 A, as expected).

As mentioned in class, the current through each resistor literally makes each resistor hot, so for R_1, e.g., the power dissipated=I^2R=4*4*5=80 Watts

$R_2=6\Omega$, $R_3=3\Omega$, $R_4=4\Omega$, $R_5=12\Omega$, $R_7=2\Omega$, $R_6=6\Omega$, $R_1=3\Omega$, $V_{battery}=24V$. ΔV_6 and $I'=?$

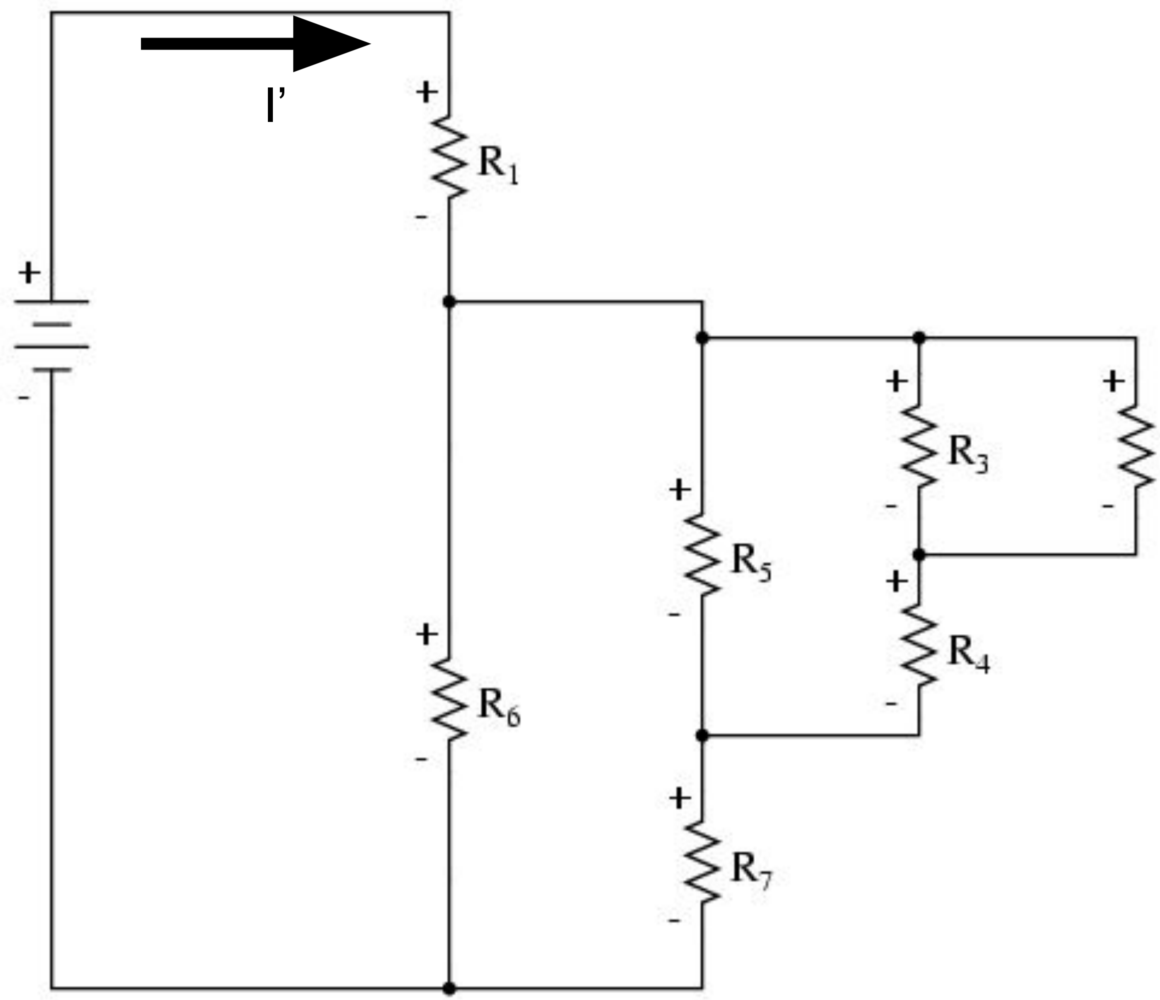
A) 8V, 1A

B) 12V, 2 A

C) 16V, 2A

D) 16V, 1A

E) NOTA



$R_2=6\Omega$, $R_3=3\Omega$, $R_4=4\Omega$, $R_5=12\Omega$, $R_7=2\Omega$, $R_6=6\Omega$, $R_1=3\Omega$, $V_{battery}=24V$. ΔV_7 and $I_5=?$

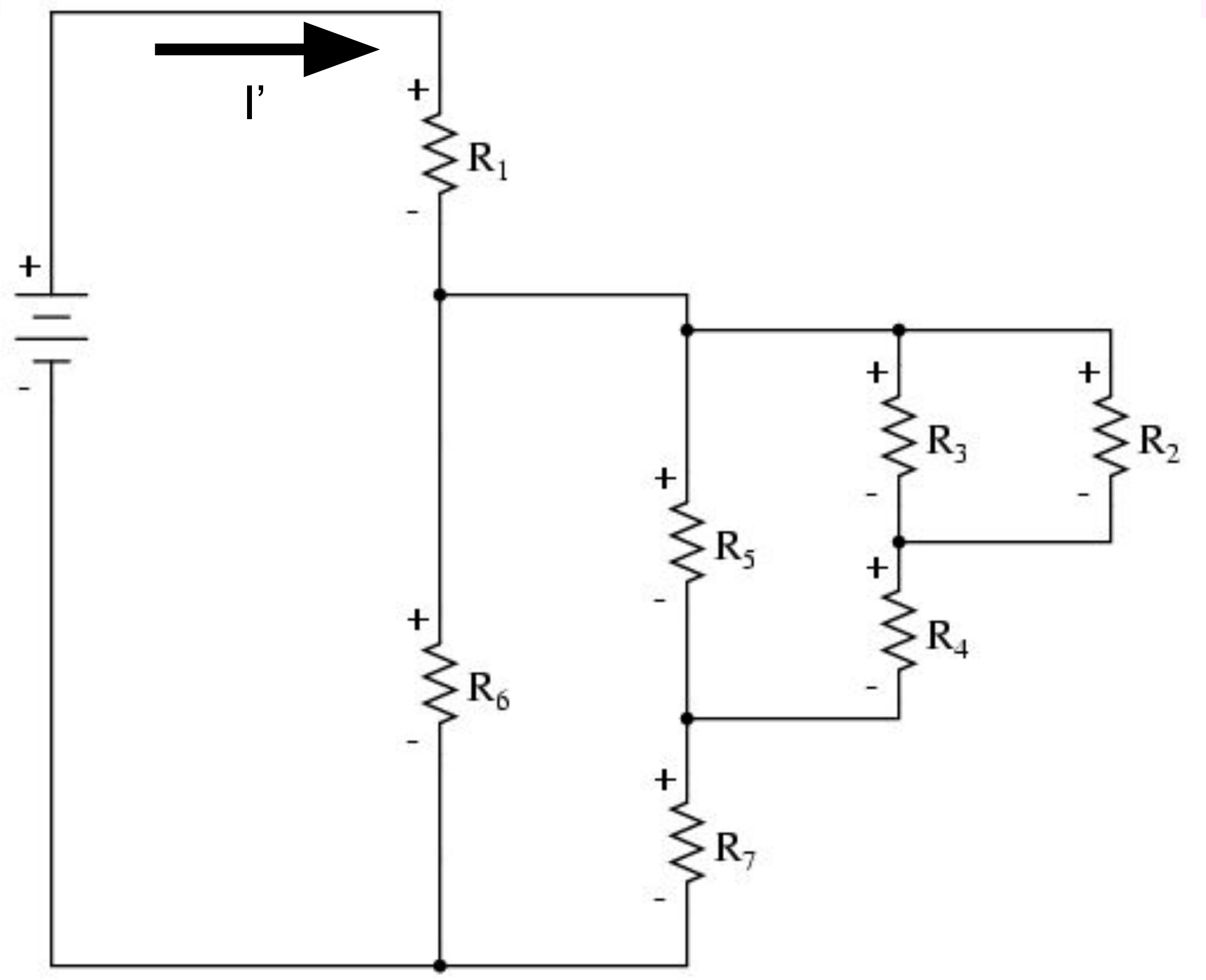
A) 4V, 2/3 A

B) 8V, 2/3 A

C) 12V, 2A

D) 16V, 1A

E) NOTA



4 light bulbs each have R=6Ω. When the switch S is opened, which bulbs burn brighter (V=144Ω)?

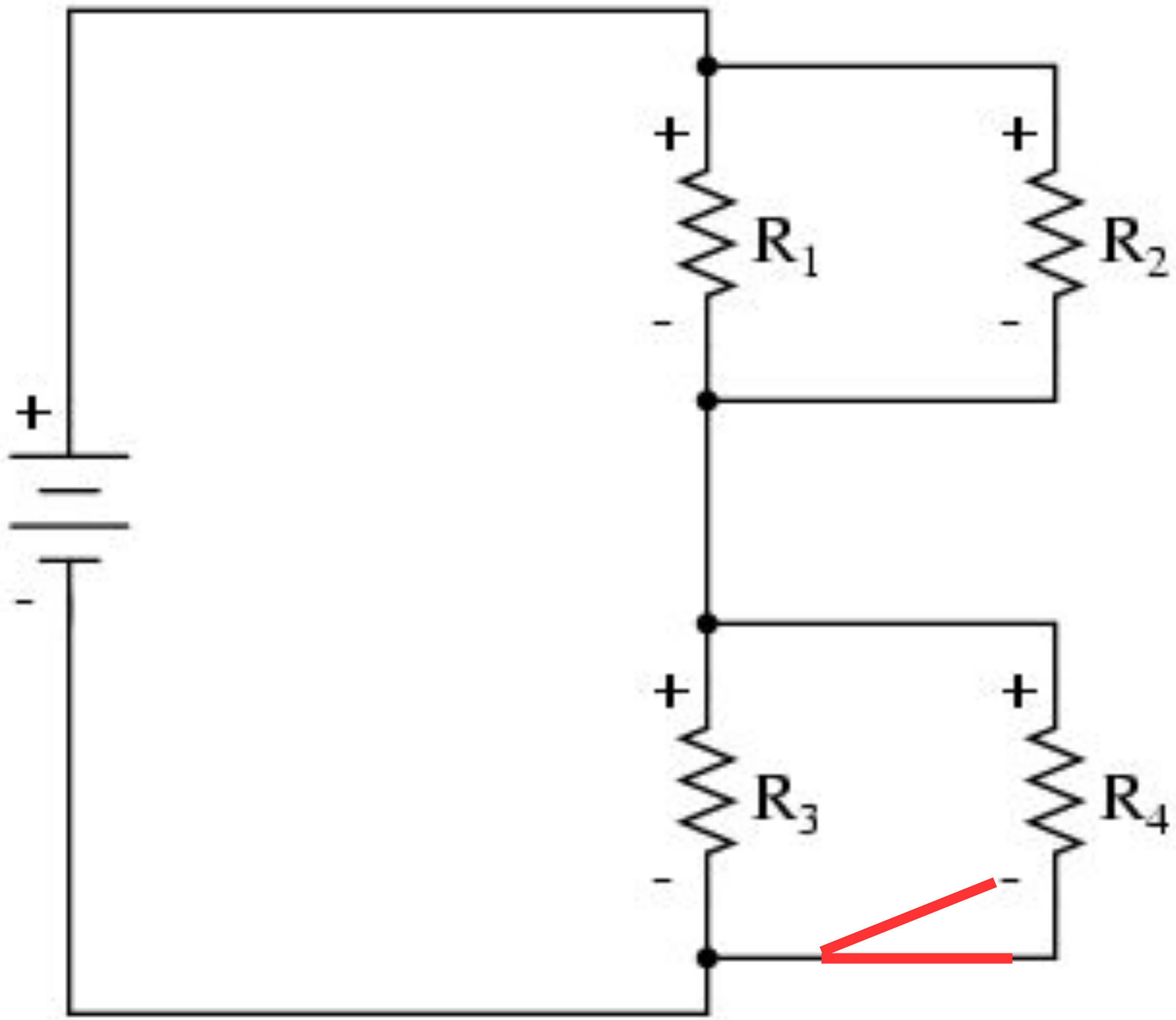
A) R1, R2, R3

B) R1 & R2 only

C) R3 only

D) All burn with the same brightness

E) NOTA



If r=1Ω, ΔV across the 2Ω resistor=

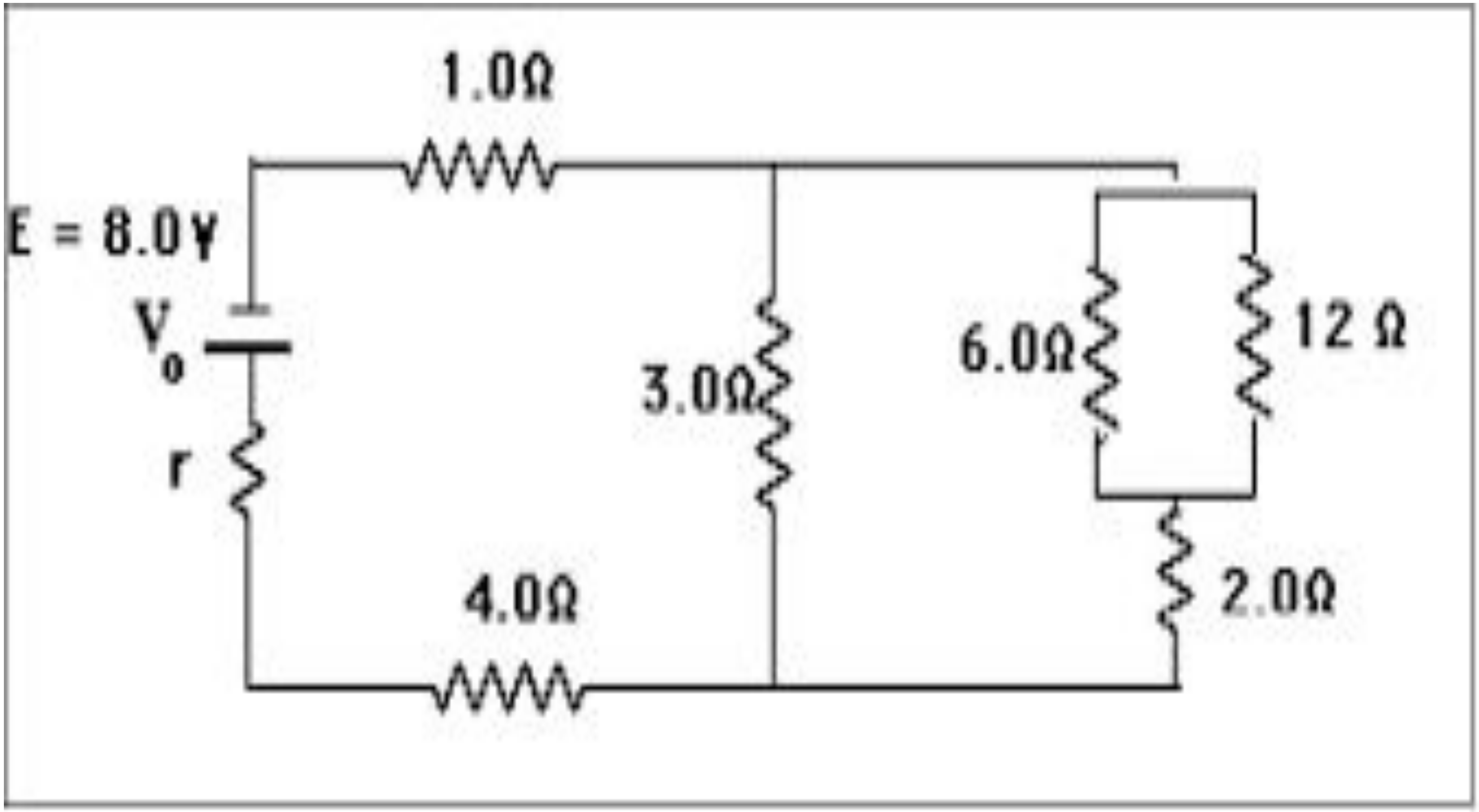
A) 1V

B) 2V

C) 2/3 V

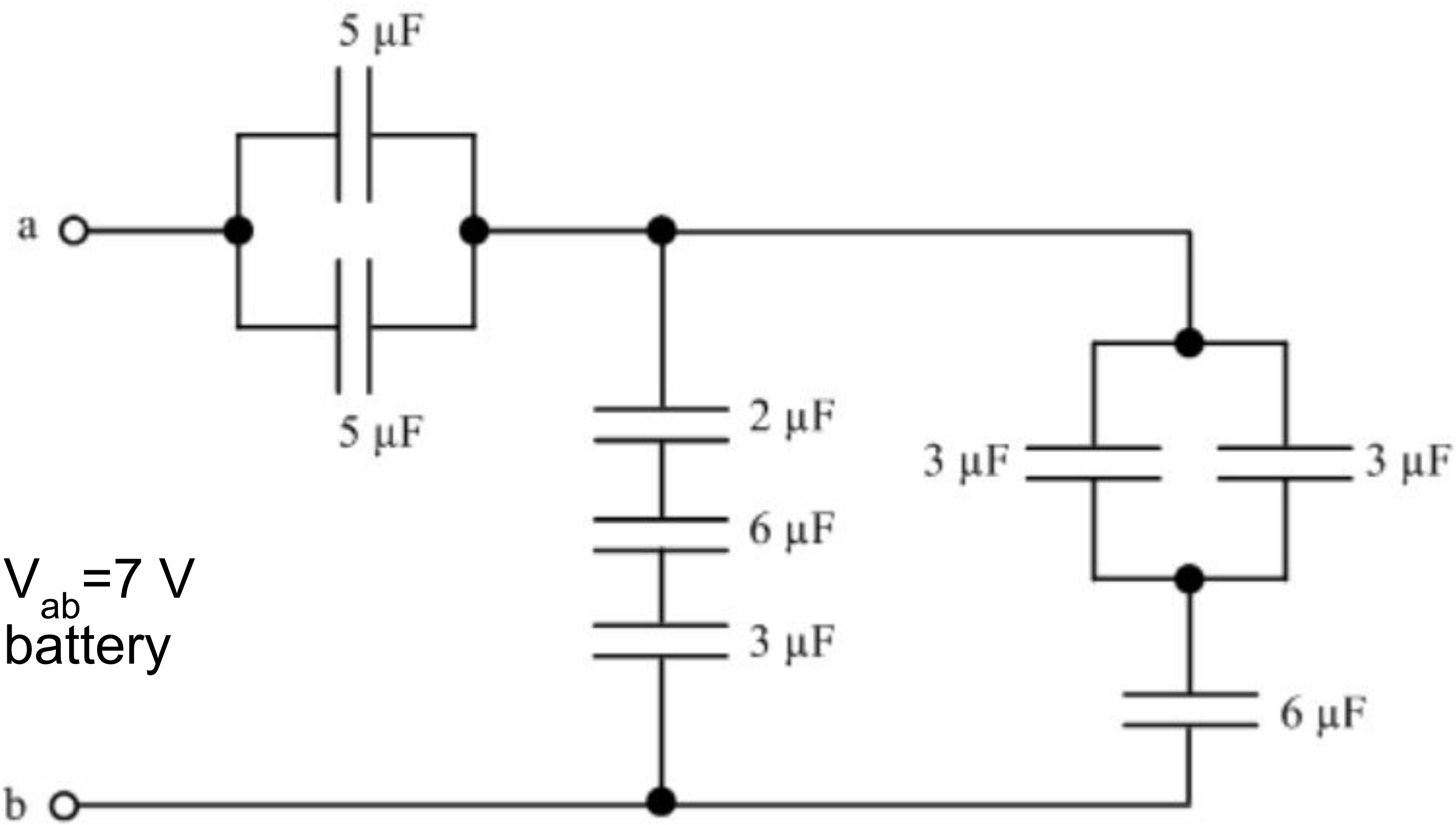
D) 4/3 V

E) NOTA

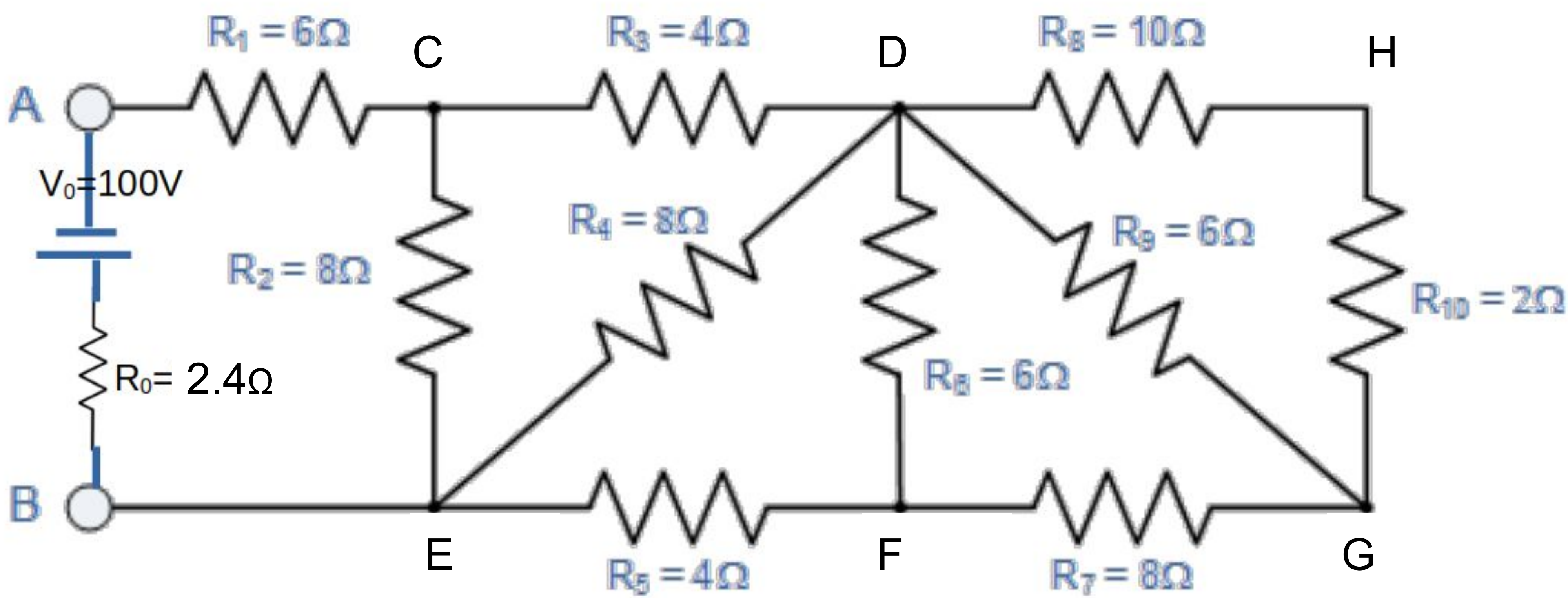


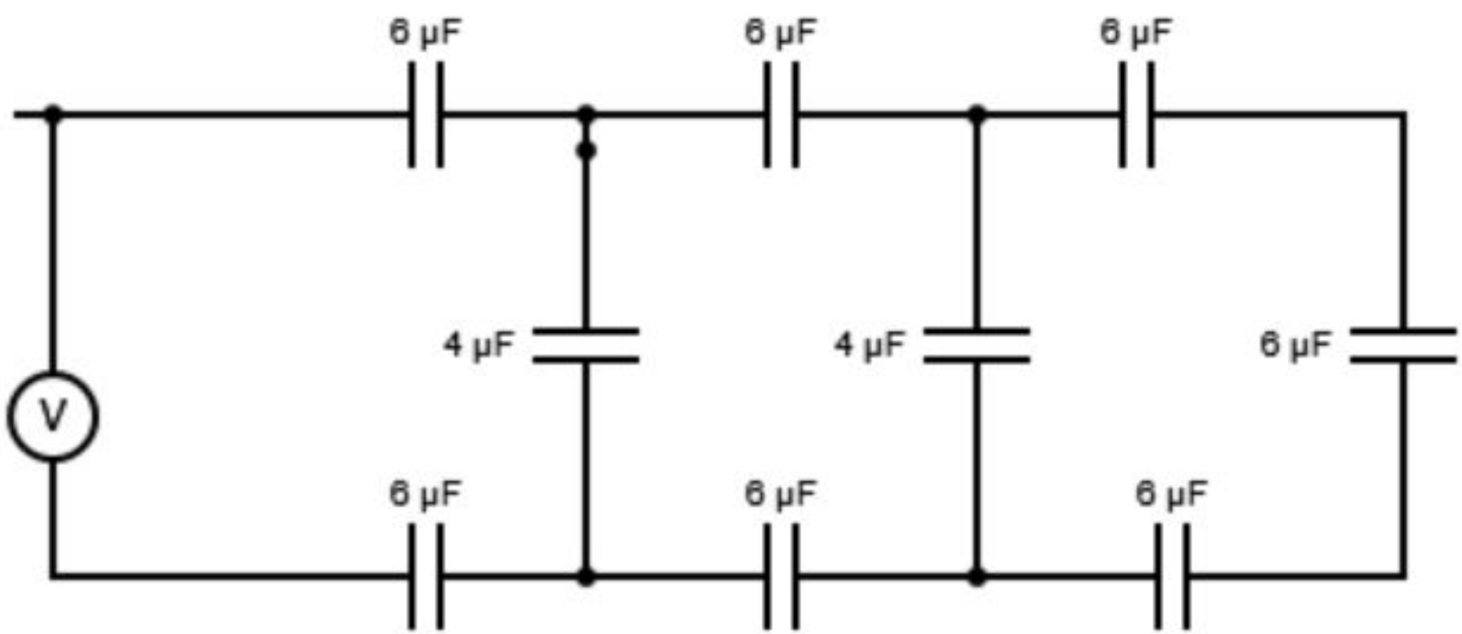
In the circuit shown, the number of individual currents would be:

A) 1 B) 2 C) 3 D) 4 E) 5



V_{ab}=7 V
battery


R1 = 6Ω
C
R3 = 4Ω
D
R8 = 10Ω
H
A
V0=100V
R4 = 8Ω
R9 = 6Ω
R2 = 8Ω
R10 = 2Ω
R0= 2.4Ω
R6 = 6Ω
B
E
R5 = 4Ω
F
R7 = 8Ω
G


6 μF
6 μF
6 μF
4 μF
4 μF
6 μF
V
6 μF
6 μF
6 μF

How many currents are needed to fully describe the circuit below?

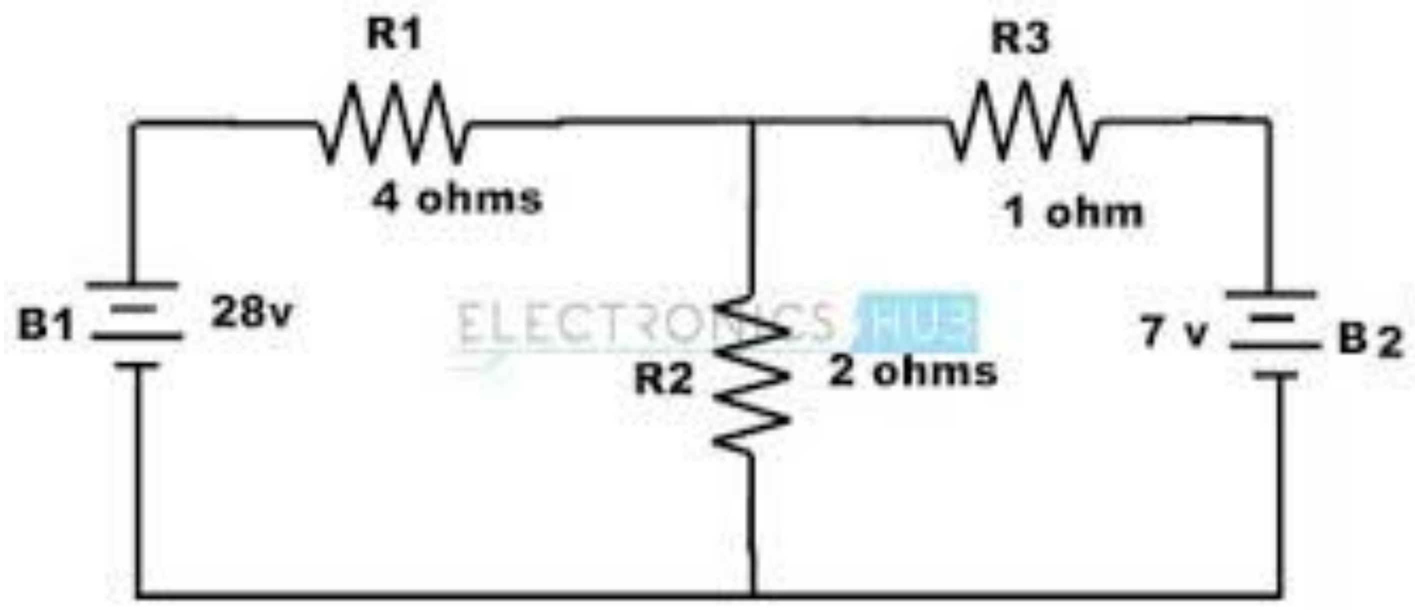
A) 1

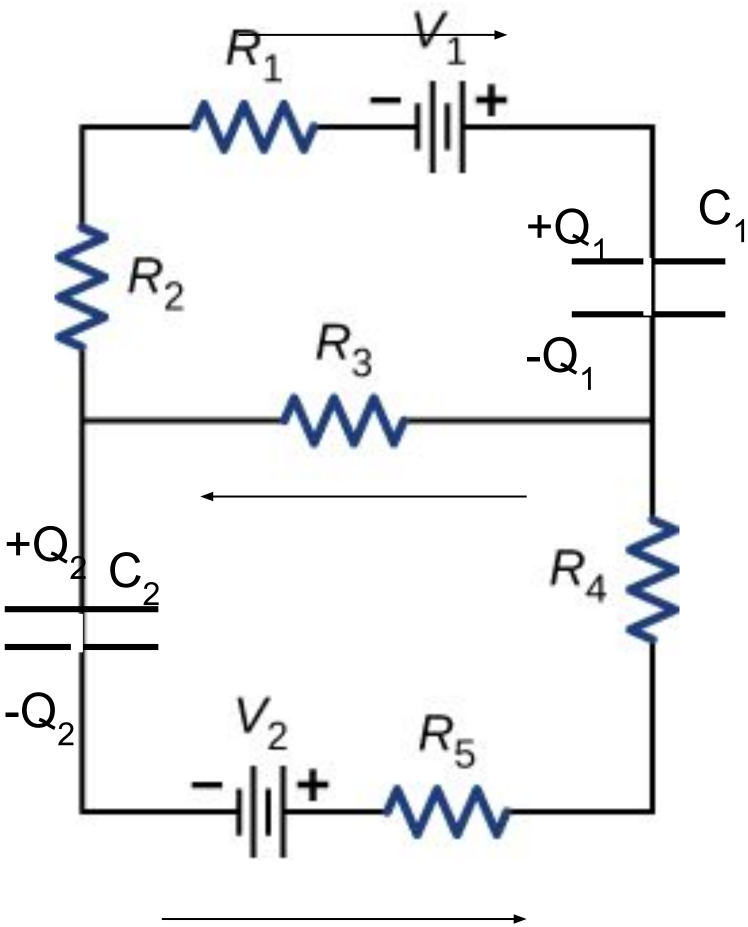
B) 2

C) 3

D) 4

E) NOTA





1. Guess current flow direction in all branches
=> →through R_1 and R_5; reverse for R_3
2. Based on current flow direction, assign +/- sides for Caps
=> top of C_1 positive; bottom of C_2 negative
3. Write Kirchoff's Laws for any loop.
=> top loop, traced clockwise, starting at – terminal of V_1:
$+V_1-Q_1/C_1 - I_3R_3-I_1R_2-I_1R_1=0$
Bottom loop, traced counter-clockwise,
$+V_2-I_5R_5-I_3R_3-I_5R_4-Q_2/C_2=0$
Outer loop, traced clockwise, starting at V_1:
$0=+V_1-Q_1/C_1+I_5R_4+I_5R_5-V_2+Q_2/C_2-I_1R_2-I_1R_1$
NOTE: positive sign before I_5R_4, I_5R_5 and Q_2/C_2 since tracing lower potential to higher potential; negative sign in front of V_2 since tracing from + → - terminal of battery.

Current equations: $I_1=I_2$ (series) and $I_4=I_5$ (series); $I_1+I_4=I_3$

Assuming currents shown, which correctly states conservation of voltage?

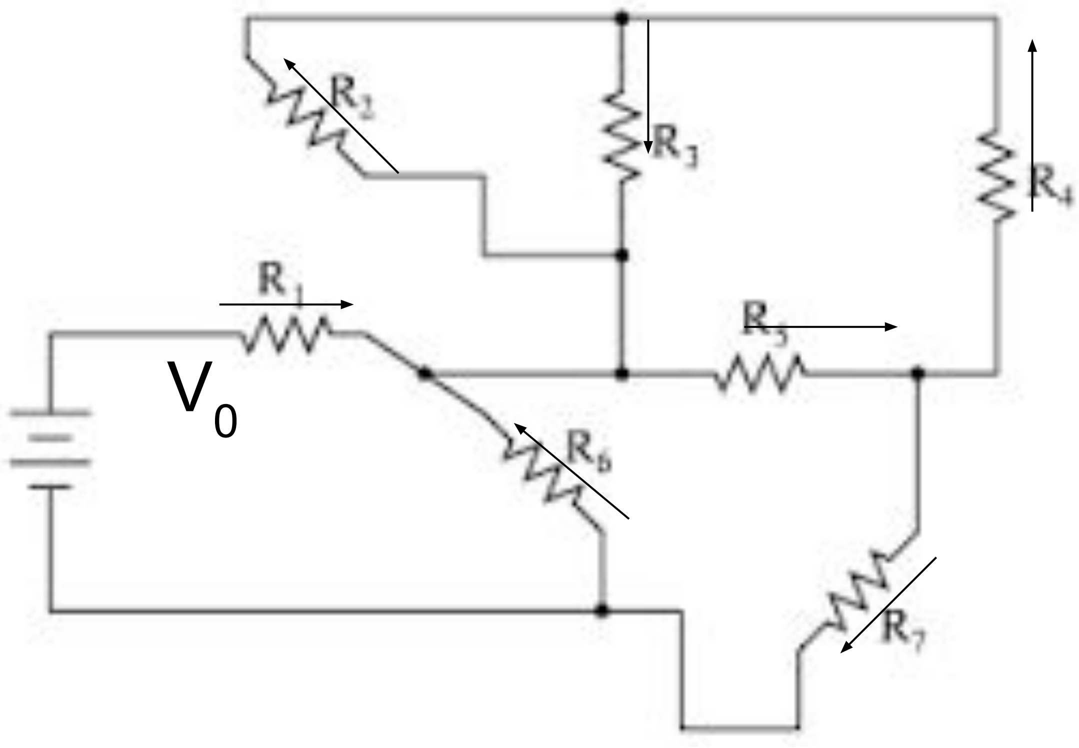
A) $V_0 - I_1R_1 - I_6R_6 = 0$

B) $V_0 - I_1R_1 + I_3R_3 + I_4R_4 + I_7R_7 = 0$

C) $V_0 + I_1R_1 + I_3R_3 + I_4R_4 + I_7R_7 - I_5R$

D) $-V_0 + I_7R_7 - I_4R_4 - I_3R_3 + I_1R_1 = ($

E) NOTA



You measure the voltages at the indicated points, from which you can guess:

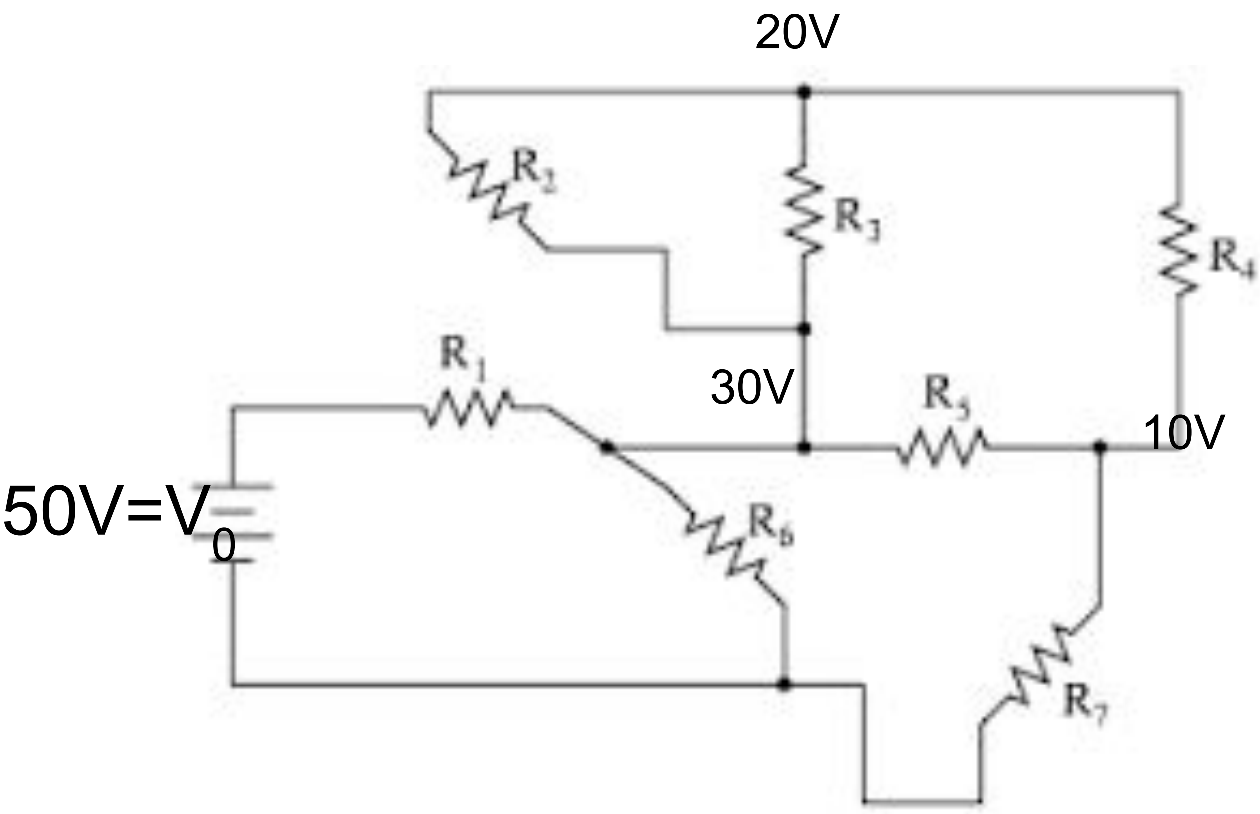
A) I_4 flows in the +y direction

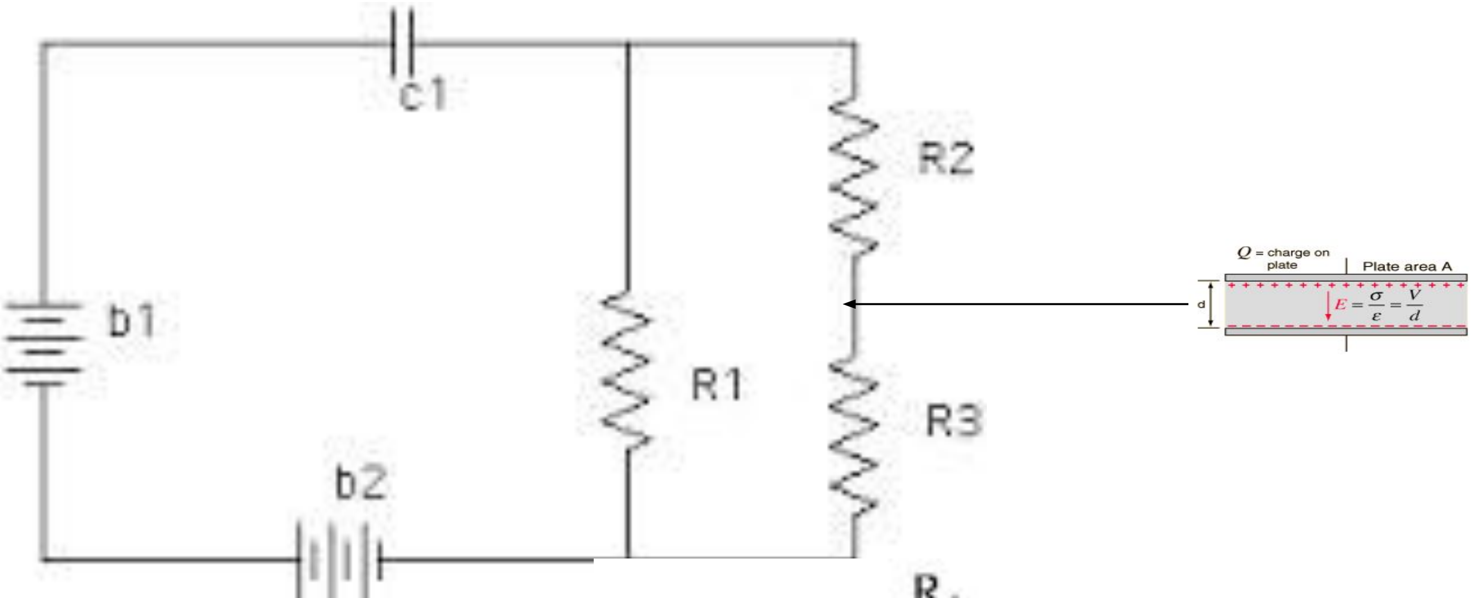
B) I_7 flows SW (↙)

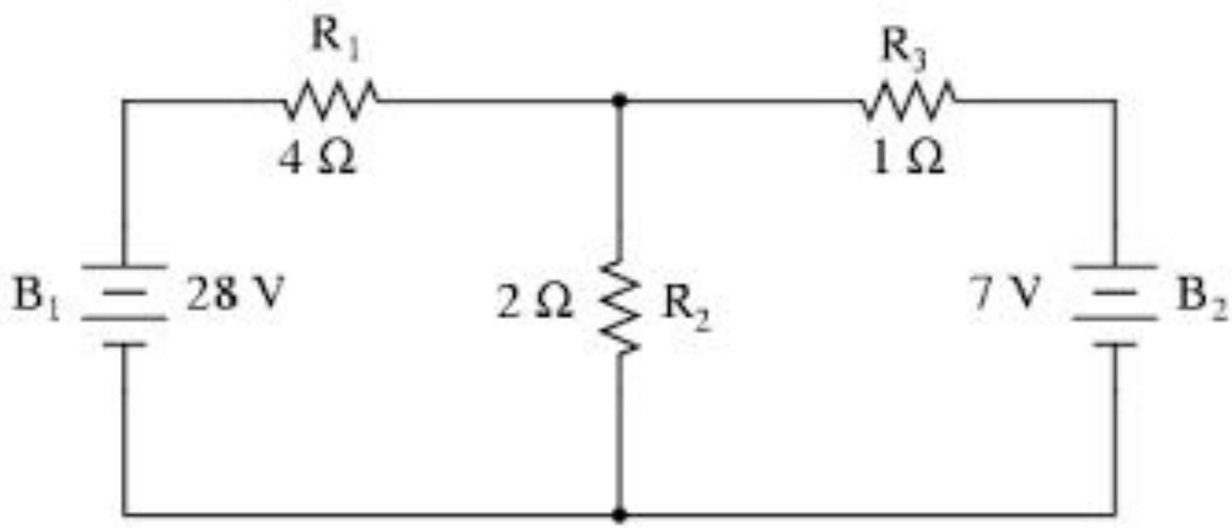
C) I_5 flows in the +x direction

D) Two of the above

E) NOTA







Multi-battery/capacitor circuits

Solve for I_1 using conservation of current/voltage; I_1=

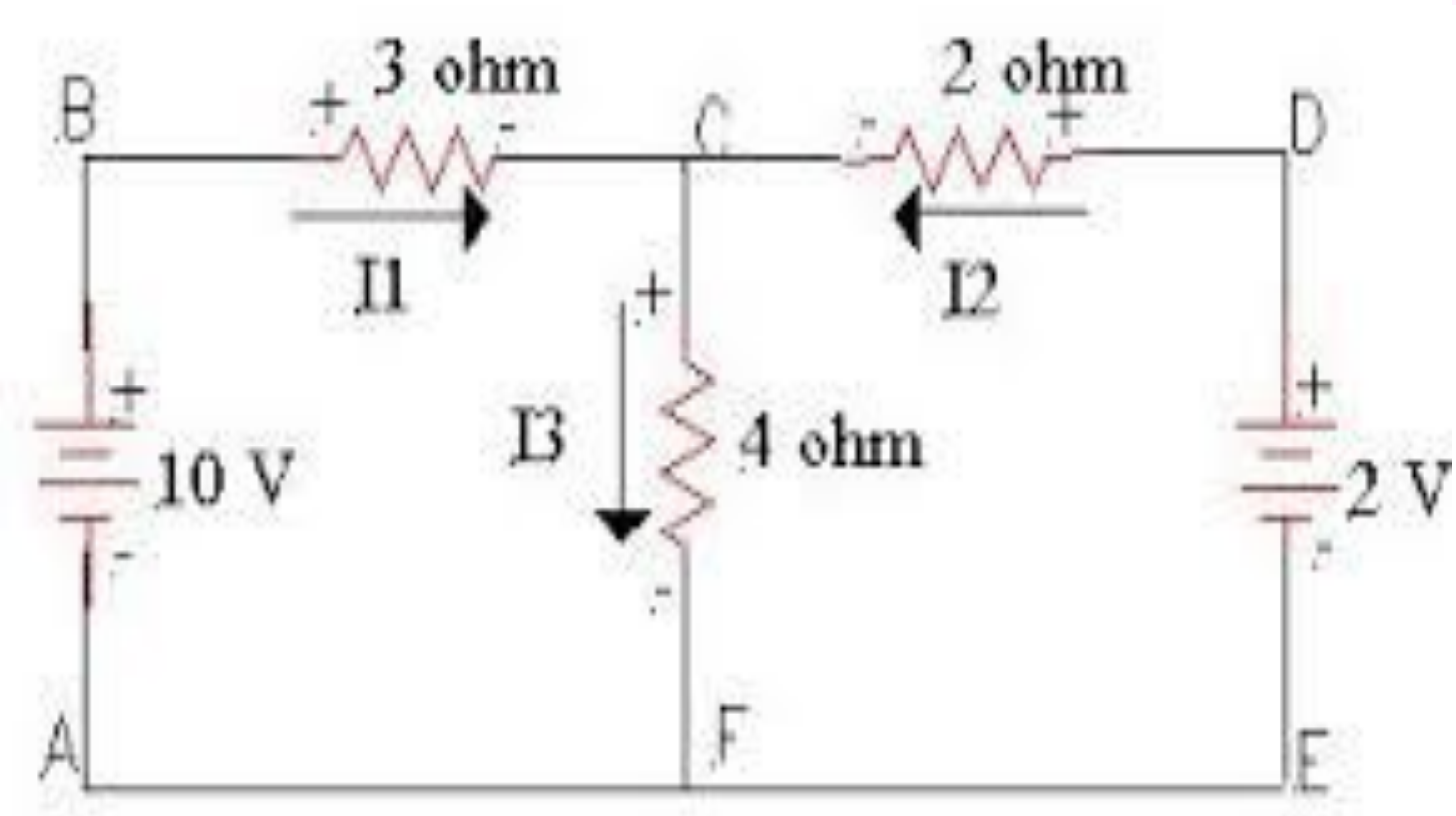
A) 1A

B) 2A

C) 3A

D) 4A

E) NOTA



The number of currents you would write to define this circuit is:

A) 1
B) 2
C) 3
D) 4
E) NOTA

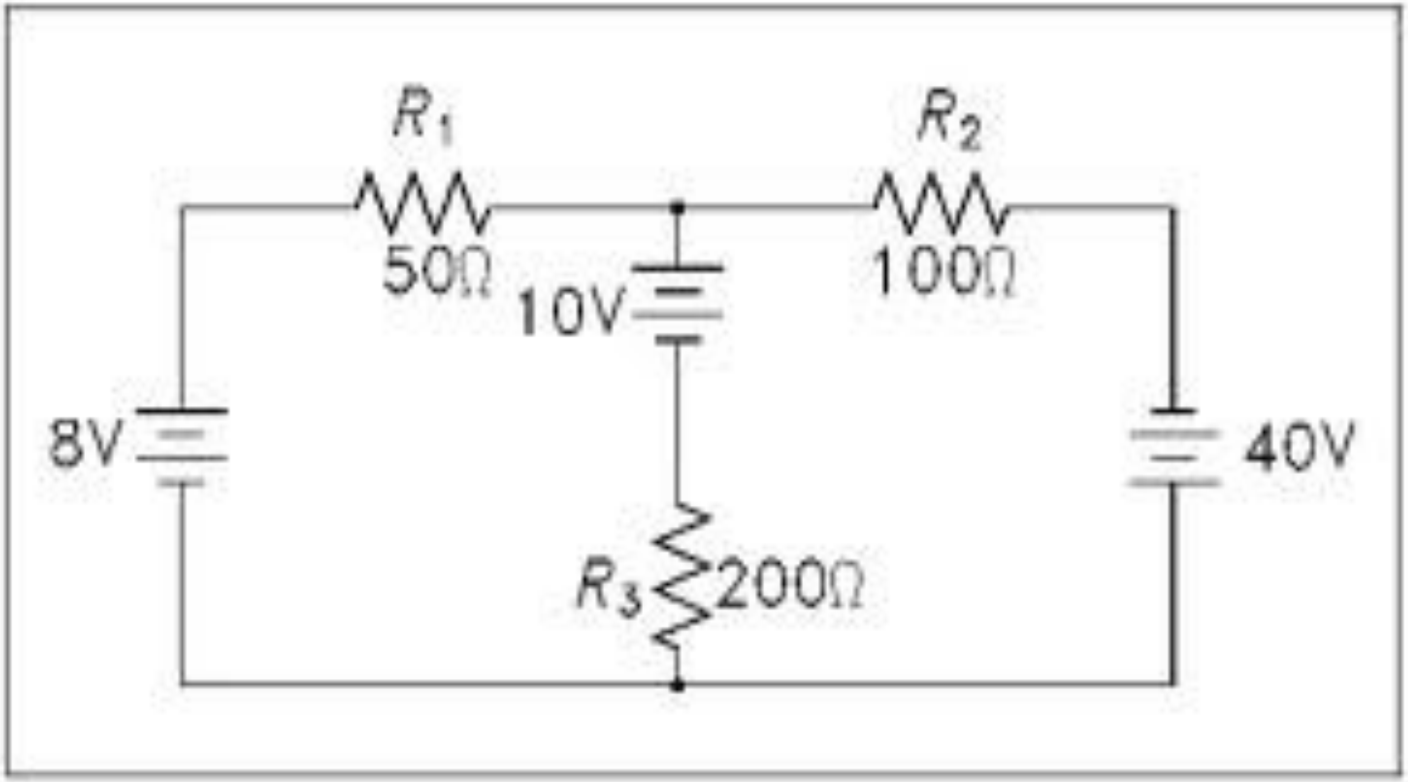
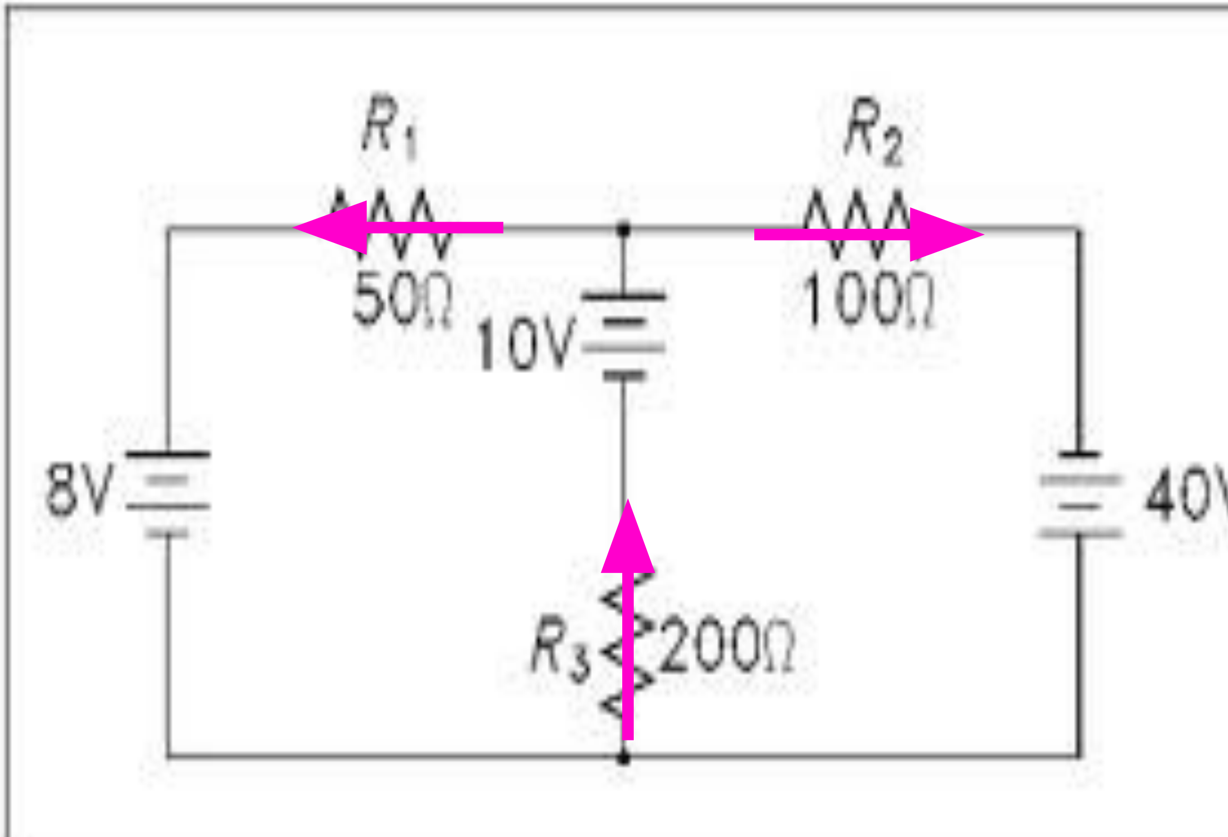


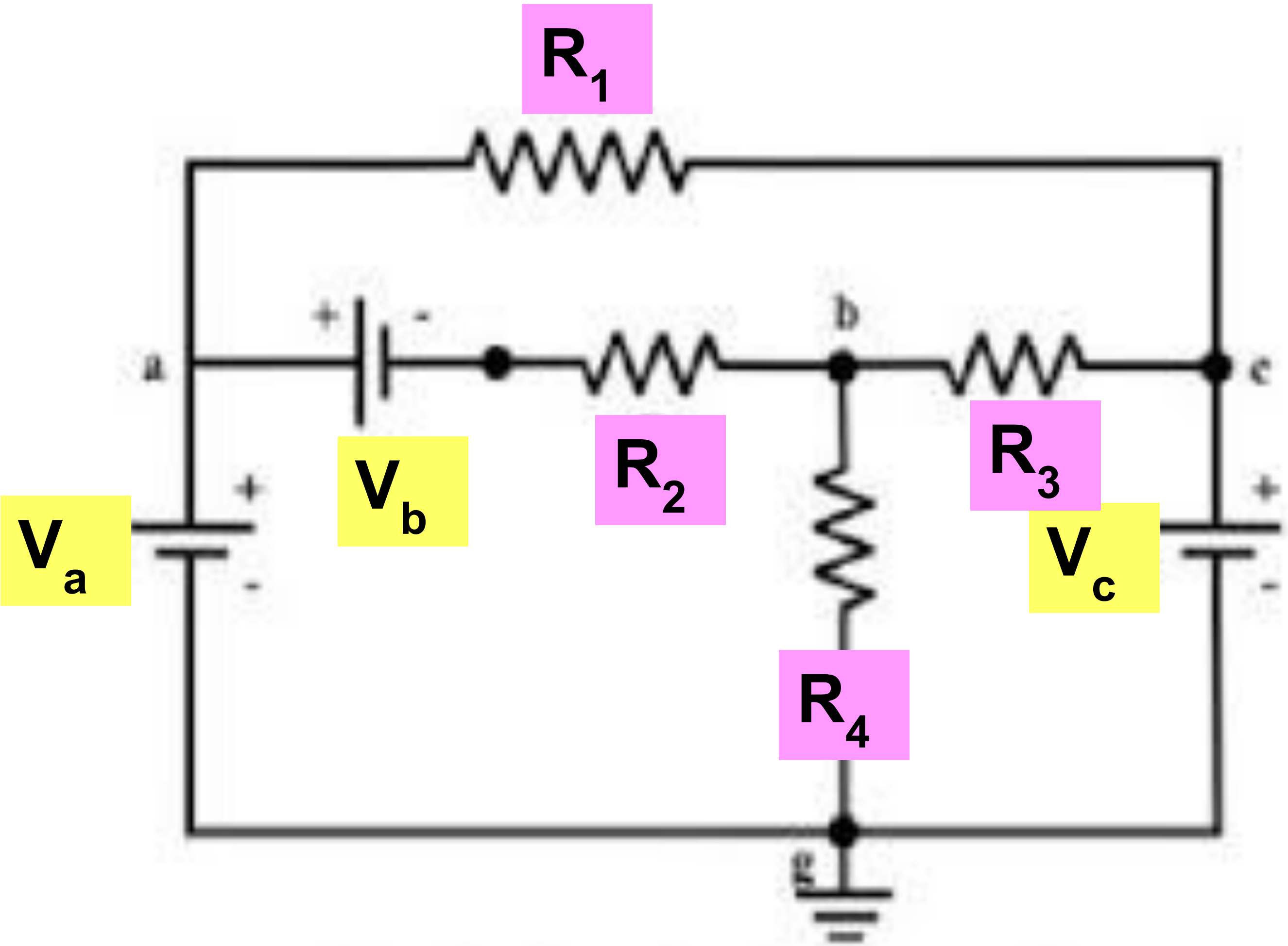
Figure 37 Example Circuit for Loop Equations

A) $200I_3+10V-50I_1-8V=0$
B) $-40V+100I_2-10V+200I_3=0$
C) $-8V-200I_3-10V-50I_1=0$
D) $40V+8V+50I_1+100I_2=0$
E) NOTA

Which eqn. above expresses voltage conservation?

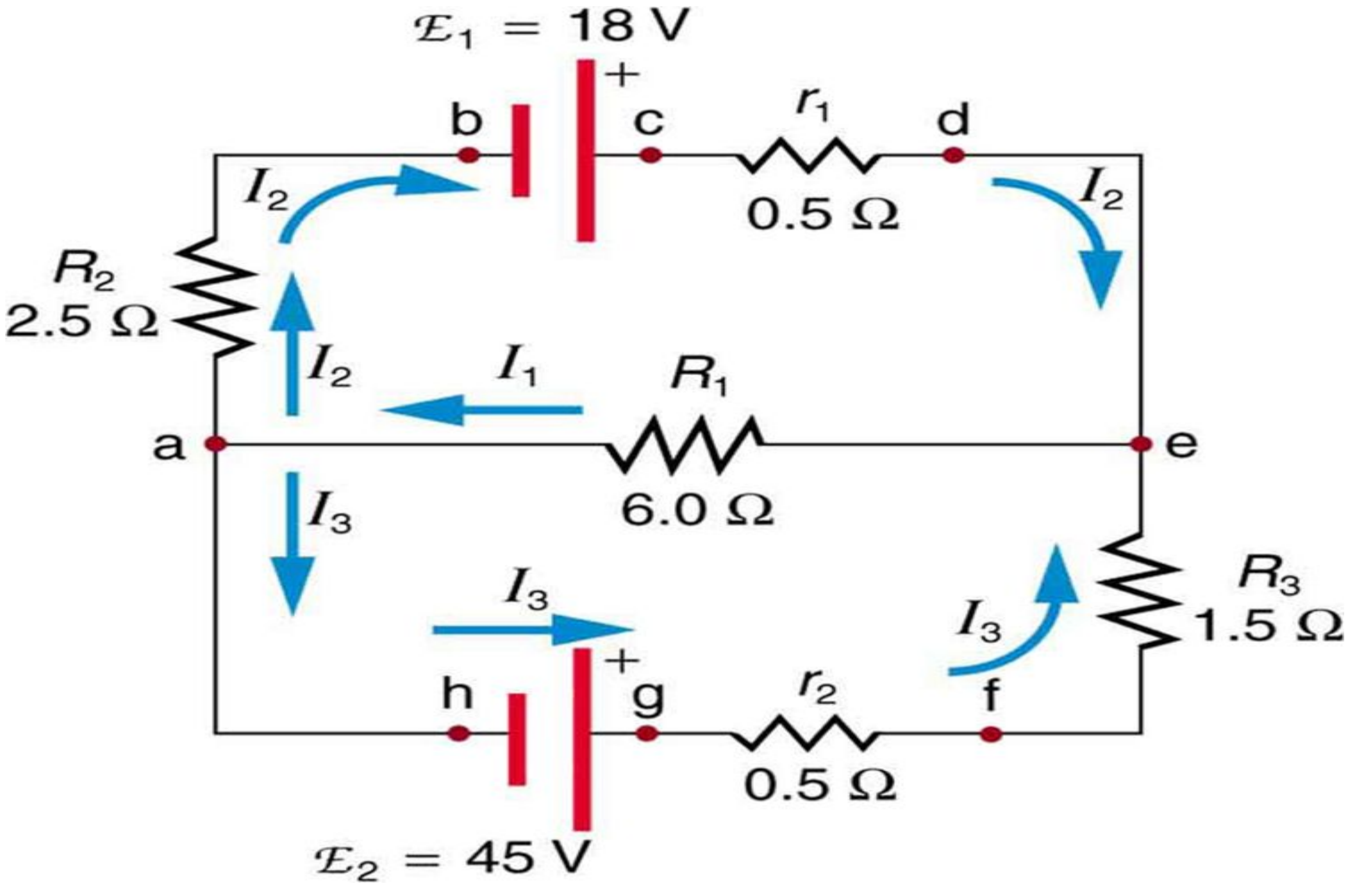


The total number of loops for which you can write conservaton of voltage is:

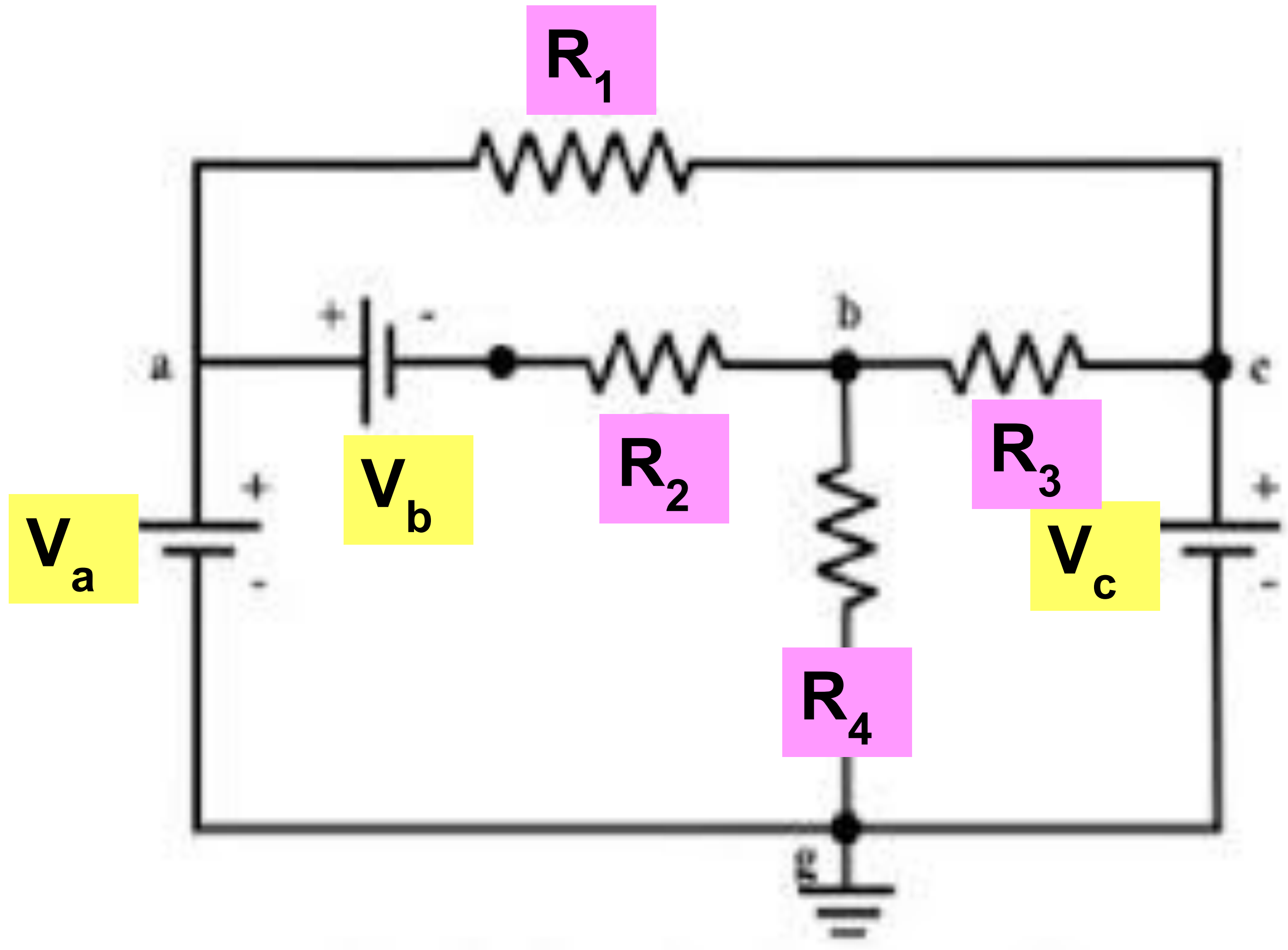


A) 3
B) 5
C) 6
D) 7
E) NOTA

Write Kirchoff's conservation of voltage and current laws for loop abcdefgh & junctions a and e



Circuits with resistors and capacitors: two limits: t=0 => branch containing the capacitor is a ‘straight wire’; t $\rightarrow$ infy => a) no current flows into branch containing capacitor, b) the capacitor charges to the point where the voltage across the capacitor is equal and opposite to the voltage being ‘pushed’ from the battery into that branch (think of what happens with water flowing through parallel pipes if one of the pipes clogs). In that limit, we can ignore the branch containing the capacitor in calculating R_{tot}.


R1
a
+
-
b
c
R2
R3
Va
Vb
Vc
R4
g

Assuming currents shown, which statement expresses conservation of voltage after the switches are closed?

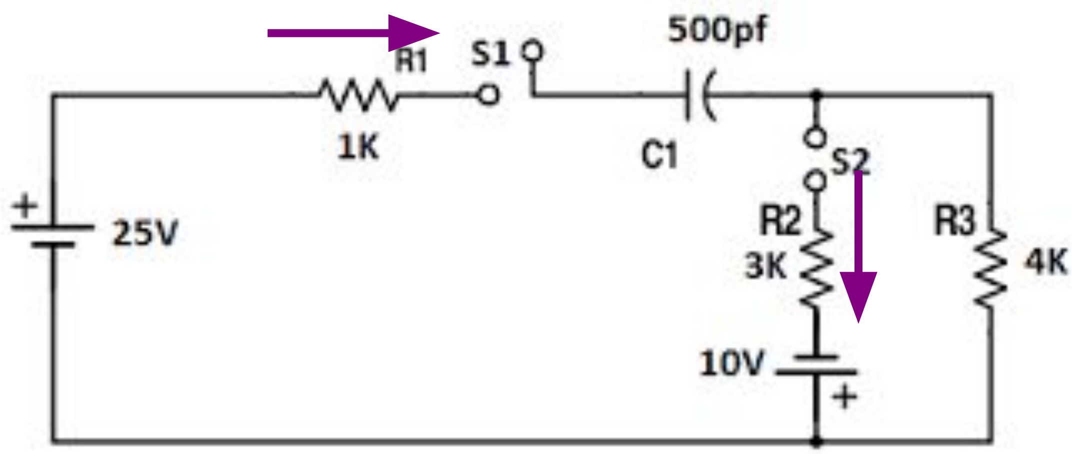
A) $25V-I_1R_1-Q_1/C_1-I_2R_2-10V=0$

B) $-25V-10V+I_2R_2+Q_1/C_1+I_1R_1=$

C) $25V-I_1R_1+Q_1/C_1-I_2R_2+10V=0$

D) $25V+I_1R_1-Q_1/C_1-I_2R_2-10V=0$

E) NOTA



If C1 were replaced by a simple wire, which would result in greater current through R3?

A) Opening S1
B) Opening S2
C) current would be the same for both A) and B) above

R_1=6Ω, R_2=12Ω, R_3=6Ω, R_4=4Ω, V=84V; C=2F. At t=0, I_3=

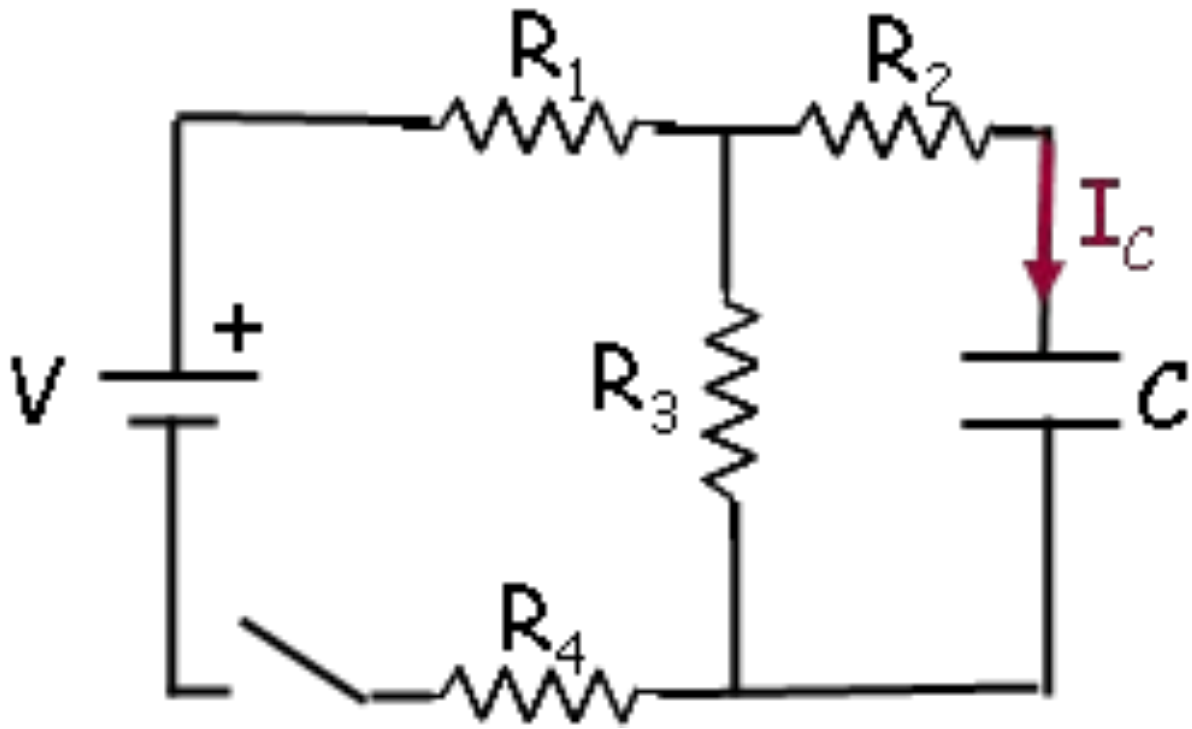
A) 4.57A

B) 6A

C) 4A

D) 12A

E) NOTA



R_1=6Ω, R_2=12Ω, R_3=6Ω, R_4=4Ω, V=96V; C=2F. At t=infty, I_3=

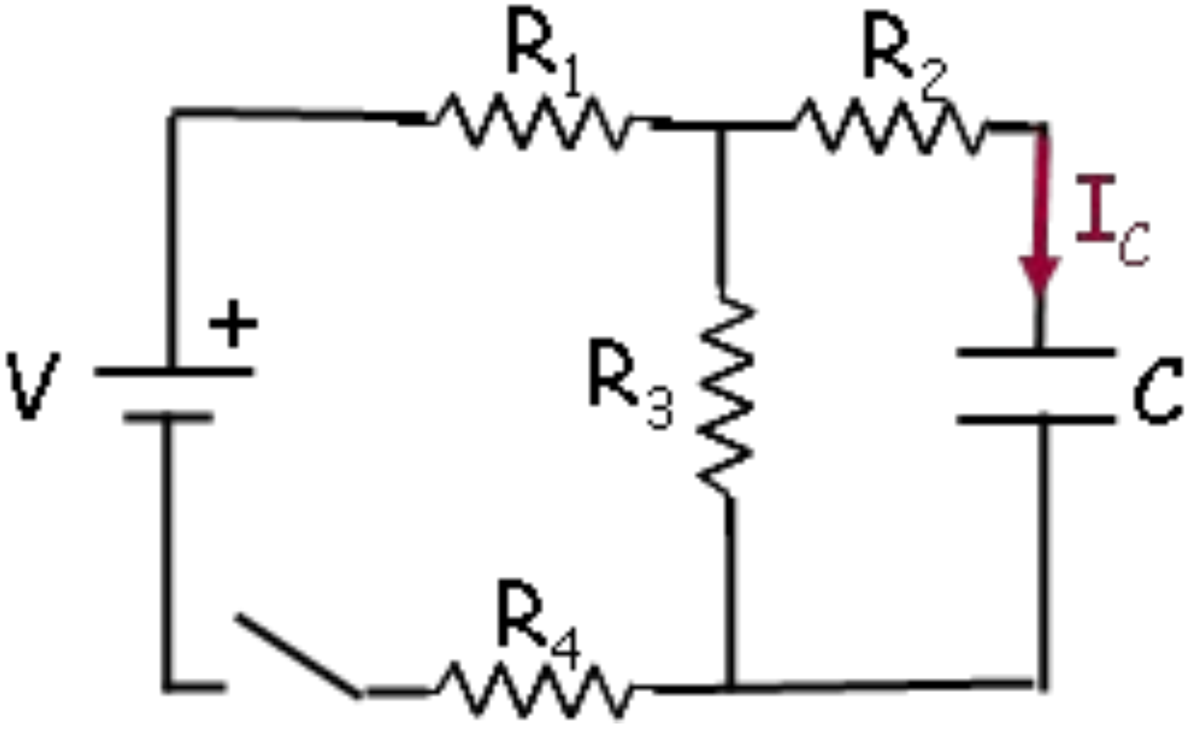
A) 4.57A

B) 6A

C) 9.14A

D) 12A

E) NOTA



The charge on C as t→infty is:
A) 72C B) 24C C) 48C D) 96C E) NOTA

What is the charge on the capacitor as t→infinity?

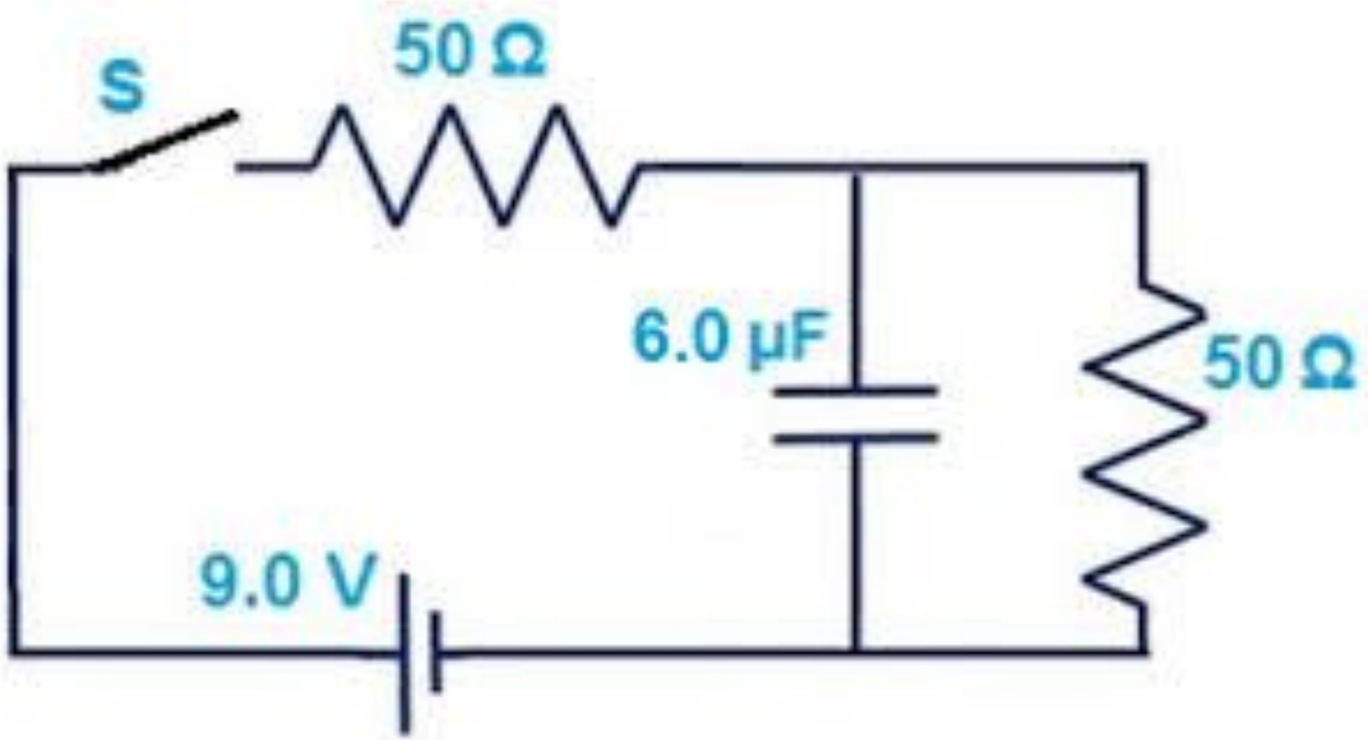
A) 24 μC

B) 27 μC

C) 30 μC

D) 9 μC

E) NOTA



What is the ratio of the current through the top resistor at t=0 vs. t→infinity?

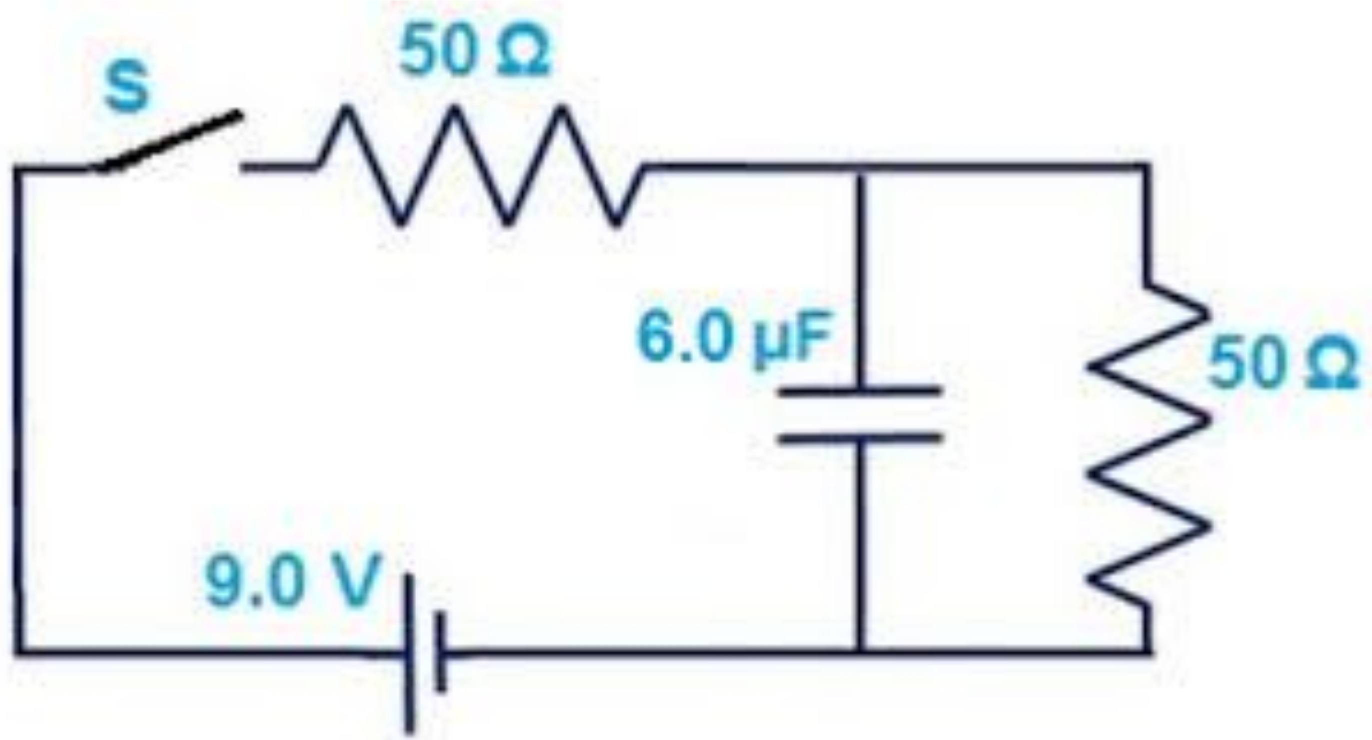
A) 0.5

B) 1.0

C) 1.5

D) 2.0

E) NOTA

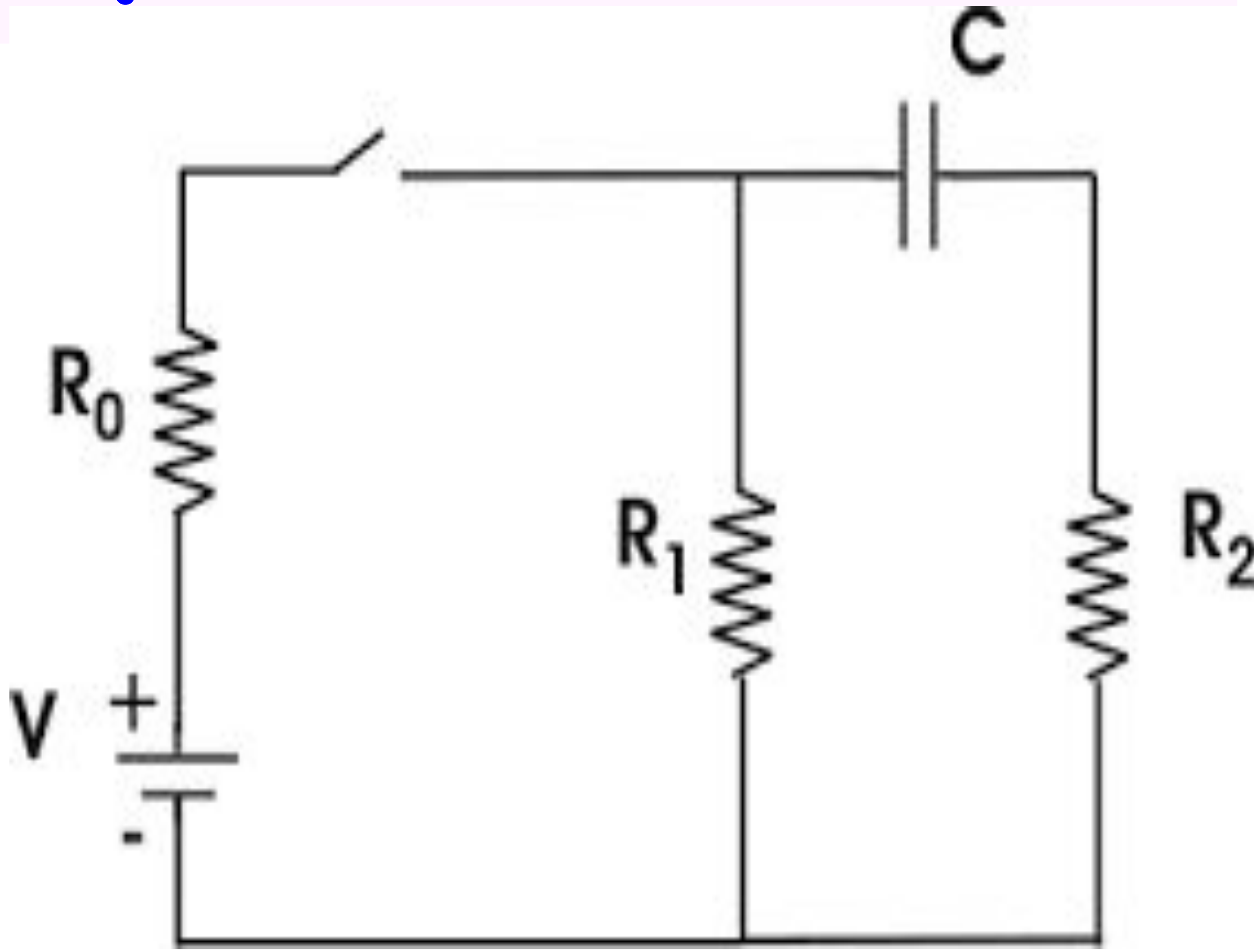


For V=12 V, C=2F, R_0=6Ω, and R_1=R_2=12Ω, how does the current through R_0 change for t=0 vs. t → infty?

A) increase

B) decrease

C) unchanged



For V=12 V, C=2F, R_0=6Ω, and R_1=R_2=12Ω, what is the ratio of voltage across R_1 at t=0 vs. t → infinity?

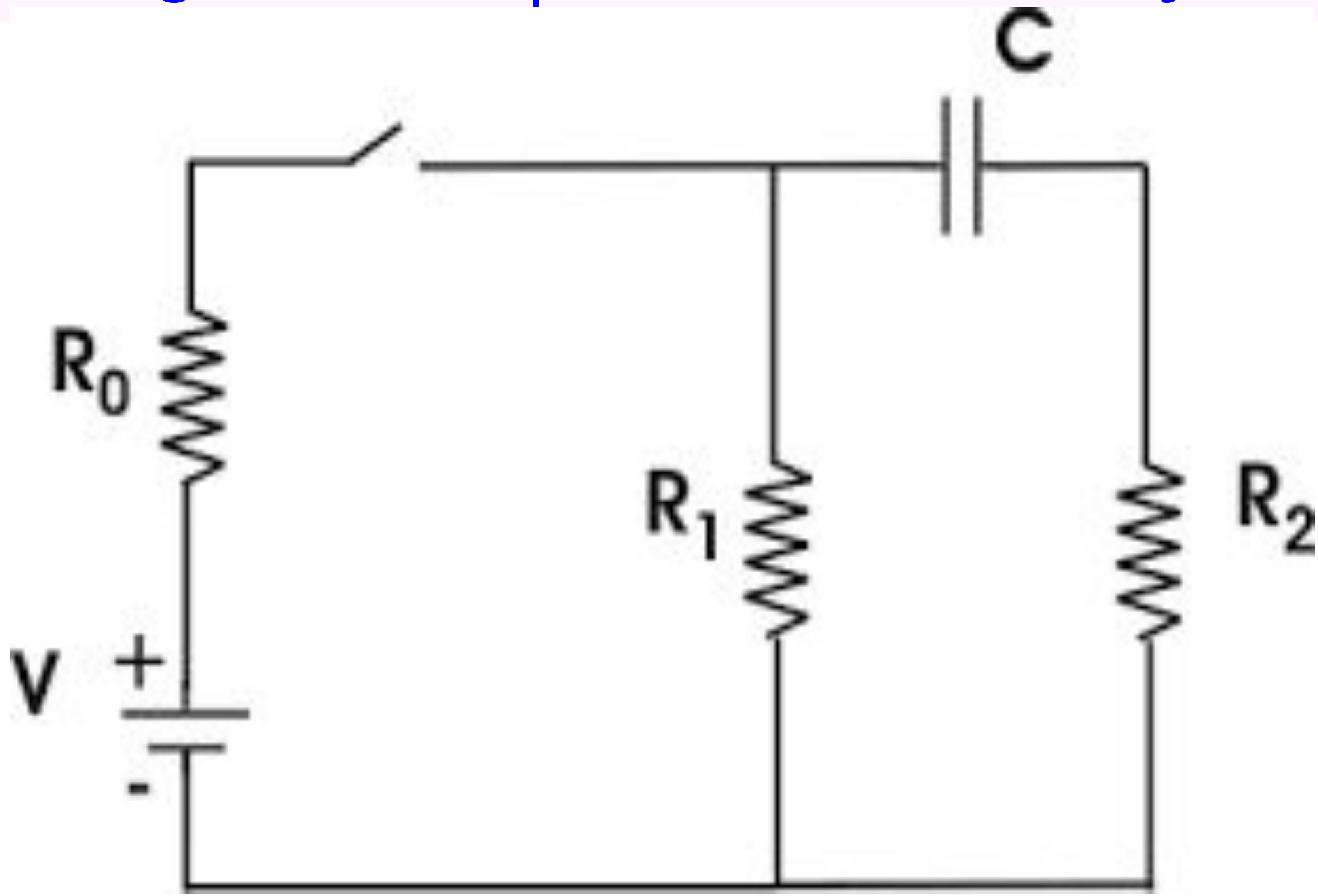
A) 1

B) 2/3

C) 3/4

D) 4/3

E) NOTA



What is the charge across the capacitor as t → infty?

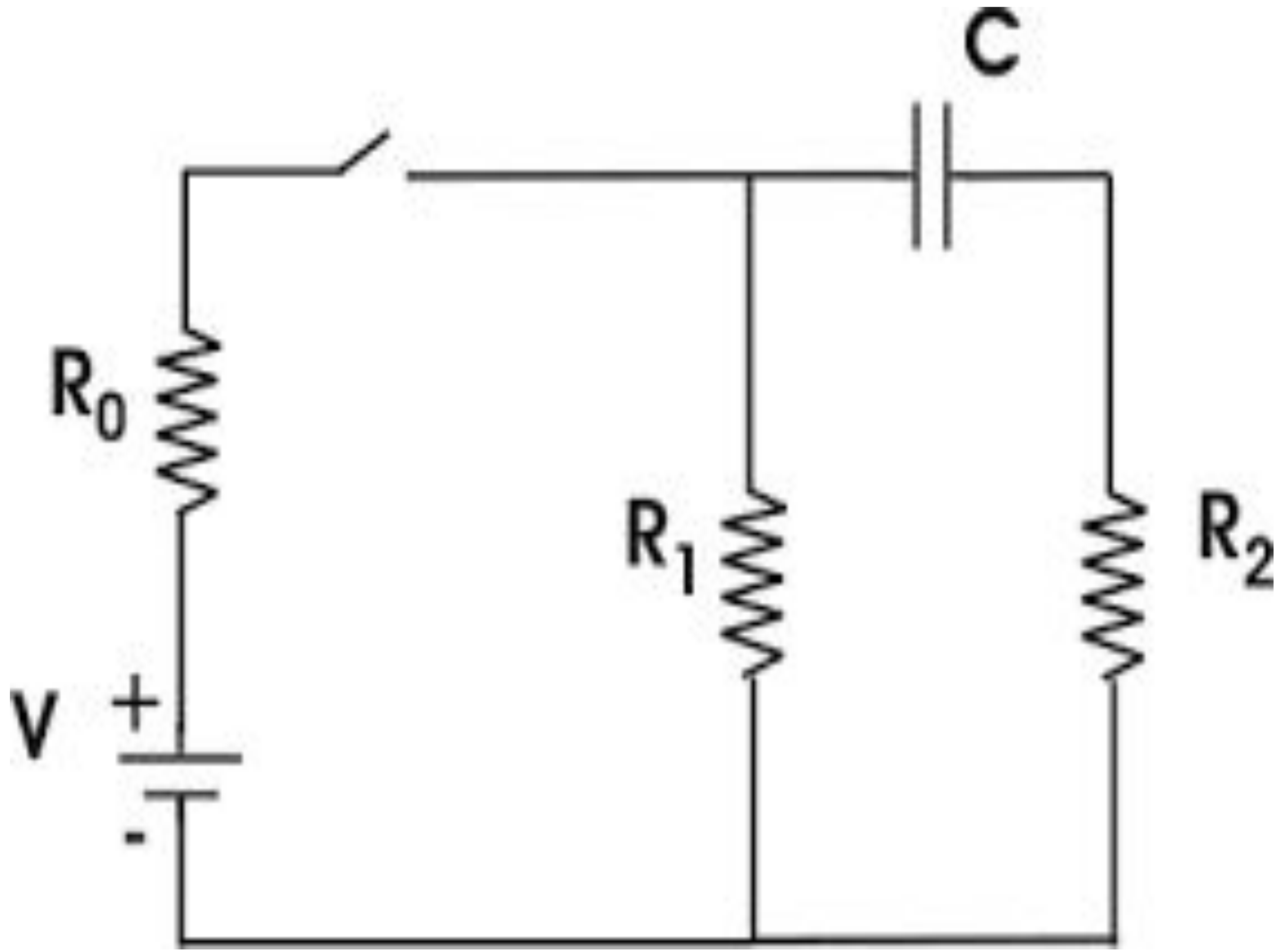
A) 4C

B) 8C

C) 16C

D) 32C

E) NOTA



If $R_0=R_1=R_2=6\Omega$ and V=24V, as $t\rightarrow$infty,

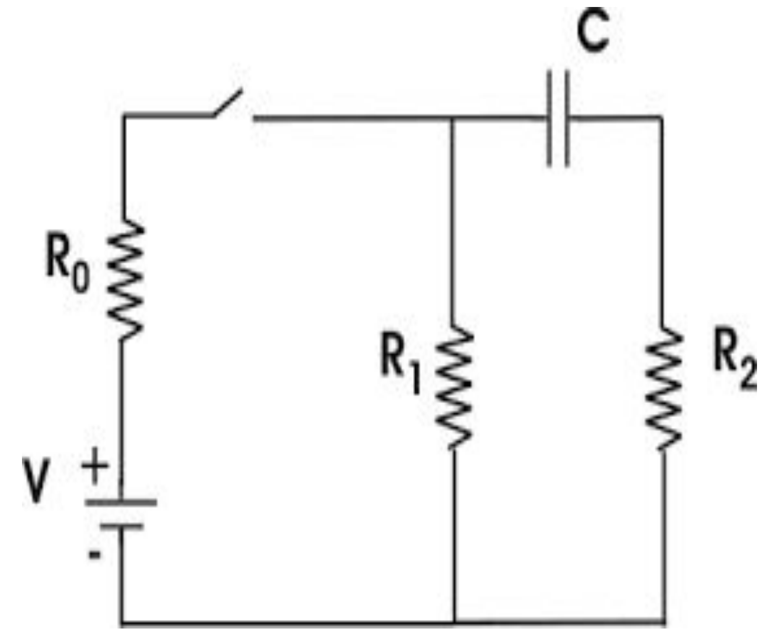
A) The voltage drop through R_2 is the same as for R_1

B) The voltage drop through C is the same as for R_0

C) The voltage drop through C is the same as for R_1

D) There is no longer any current thru resistor R_2

E) At least two of the above are true



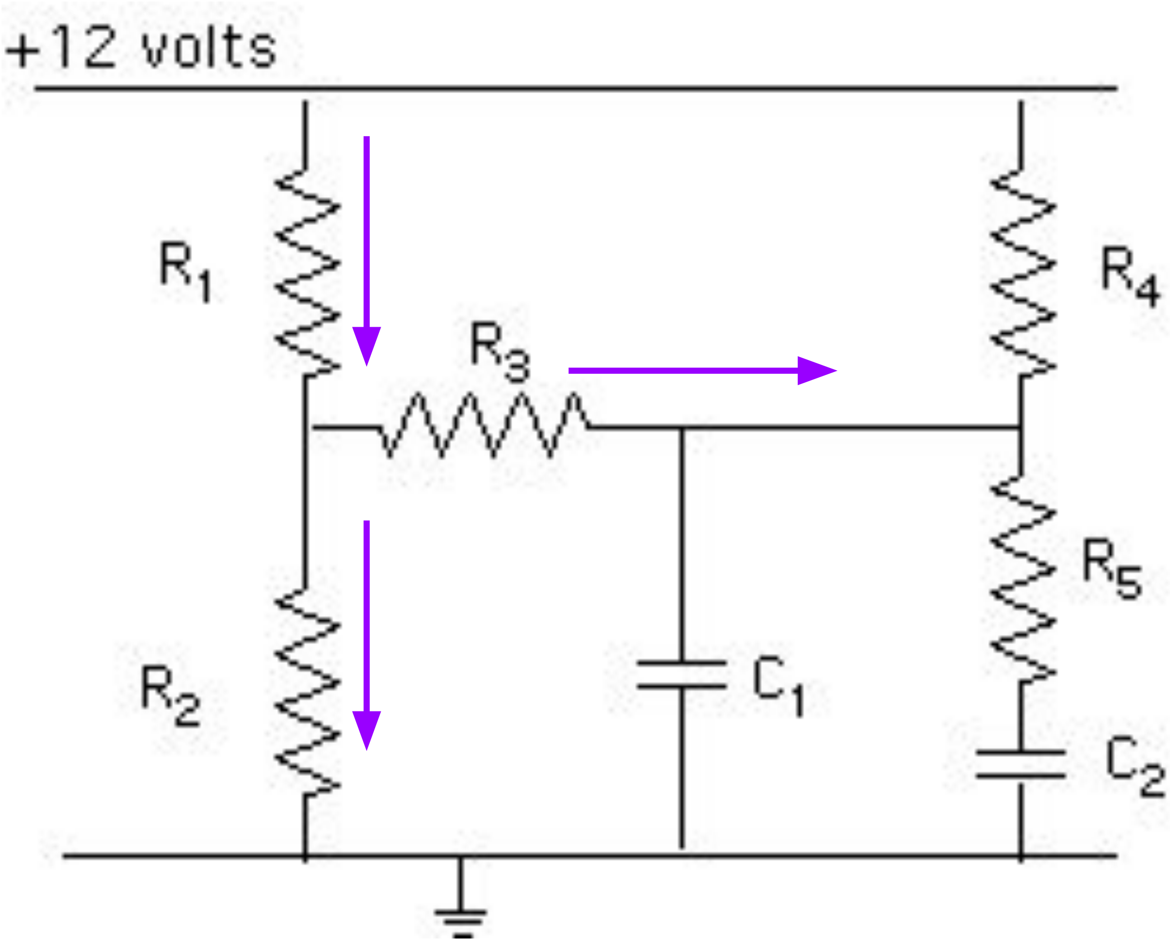
If the current direction is shown at t=0, and if $R_1=R_2$, then, at that time:

A) $V_2=V_1$

B) $V_2>V_1$

C) $V_2<V_1$

D) Need more info



A 3F capacitor is inserted in series with the 6 Ohm resistor. $I_{tot}(t=0)$ and $I_{tot}(t \rightarrow \text{infinity})$ are:

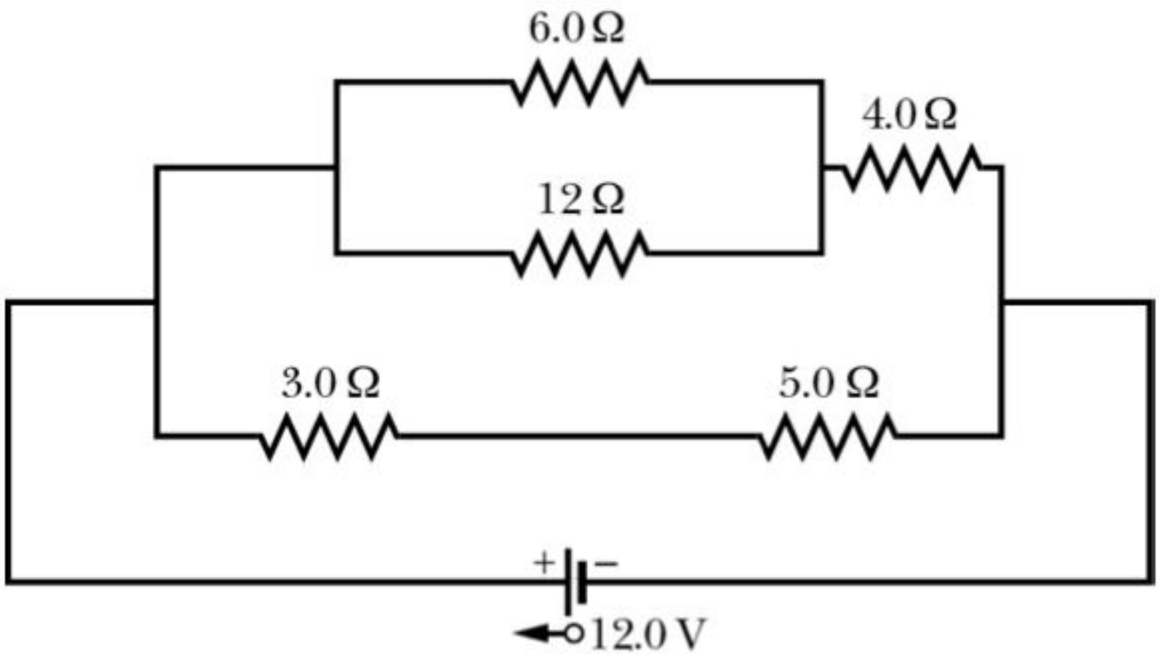
A) 1A, 0.675A

B) 1A, 1A

C) 2A, 0.8A

D) 3A, 2.25A

E) NOTA



A 3F capacitor is inserted in series with the 6 Ohm resistor. The current through the 3Ω resistor at t=0 and t→ infinity is:

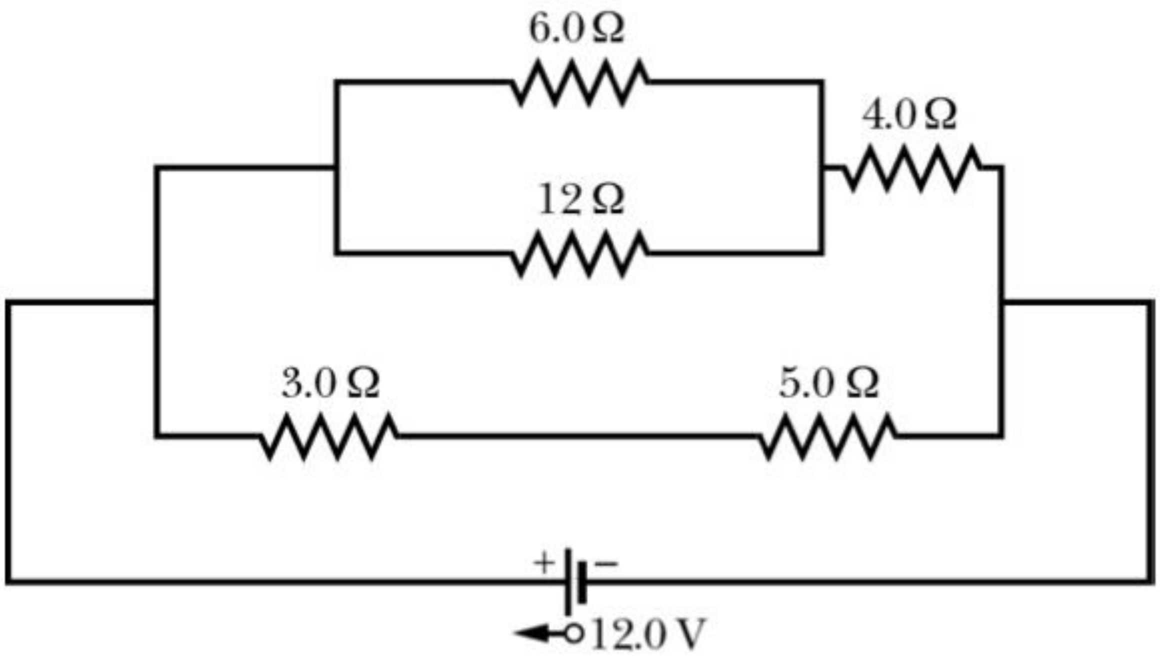
A) 1.5A, 3A

B) 1.5A, 1.5A

C) 3A, 3A

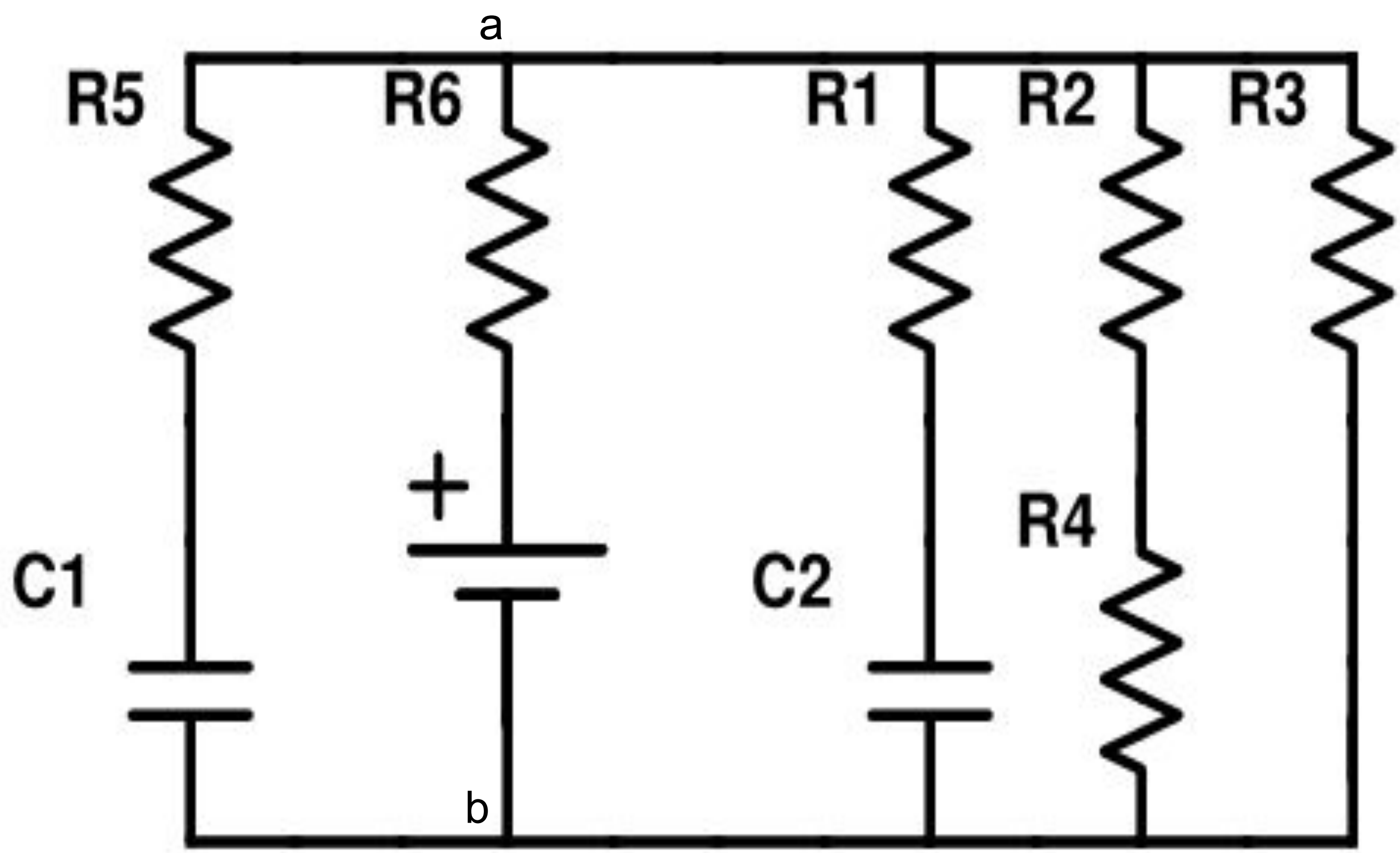
D) 3A, 1.5 A

E) NOTA



R_1=3Ω; R_2=6Ω; R_3=24Ω; R_4=2Ω; R_5=2Ω; R_6=5Ω; C_1=2F; C_2=4F; V=96V. V_4 @t=0, t→infty=

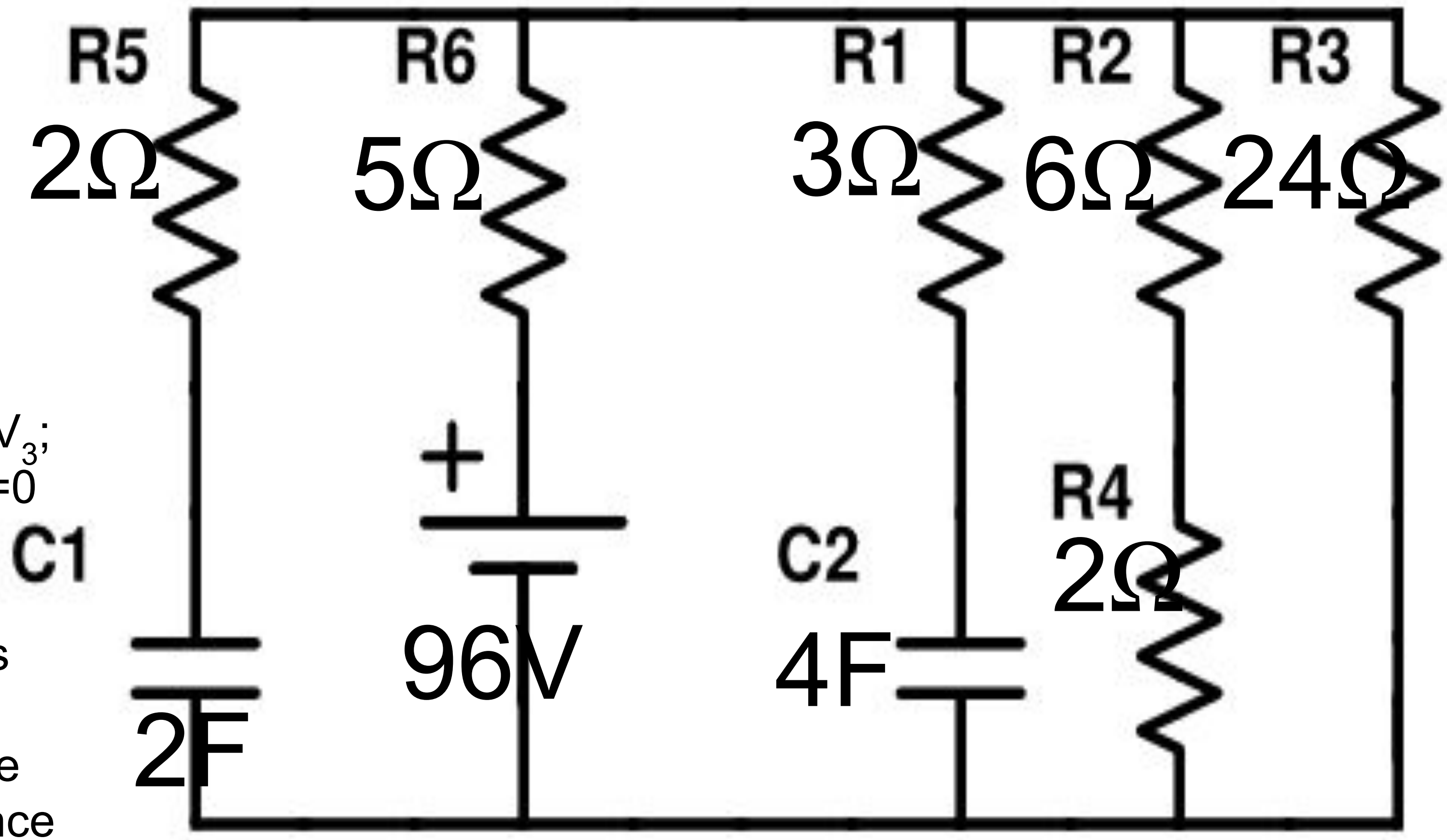
A) 2V, 8V
B) 4V, 13.09V
C) 8V, 4V
D) 6V, 6V
E) NOTA

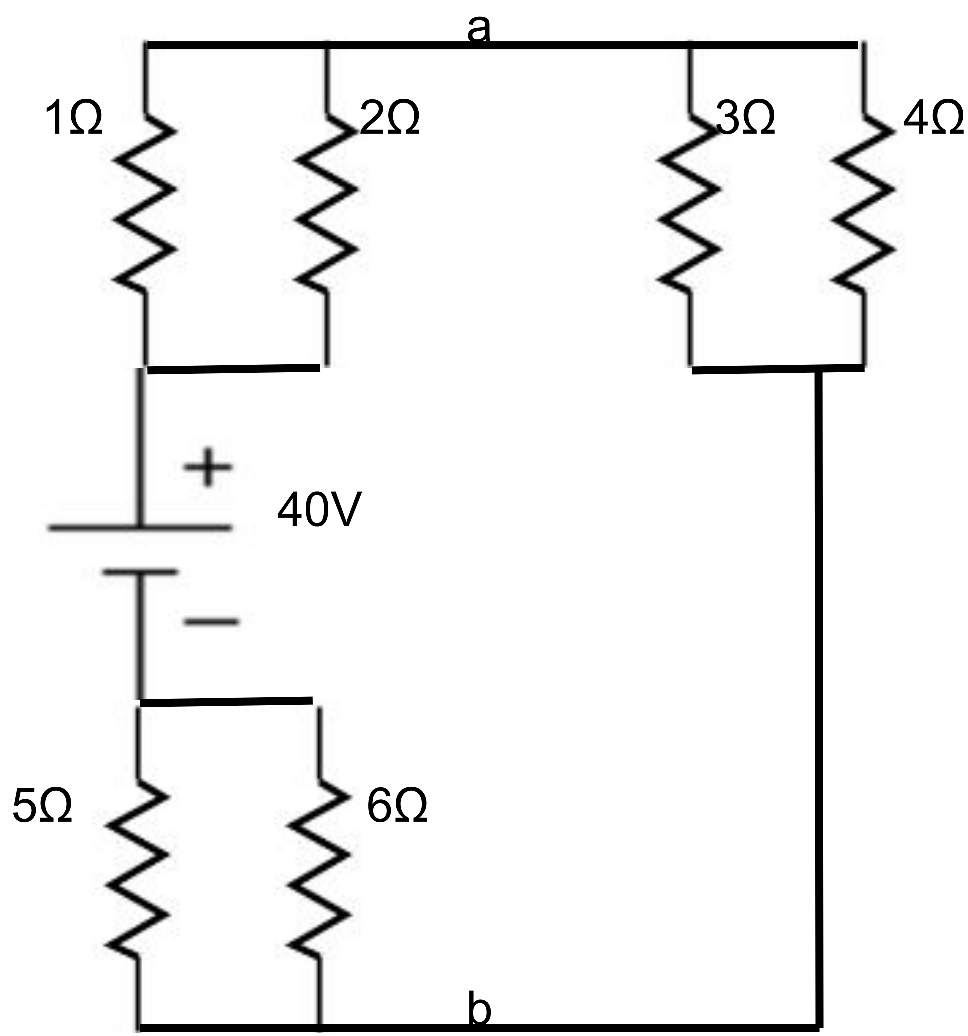


Q_1(t →infty)=A) 209.4 C B) 104.7 C C) 2C D) 192C E) NOTA

$T=0$: $R_{24}=8\Omega$;
$R_1||R_{24}||R_5||R_3$
So: $1/R_{12345}=$
$1/2+1/3+1/8+1/24 \Rightarrow$
$R_{12345}=1\Omega$, so $R_{tot}=6\Omega$, and
$I_{tot}=96/6\Omega=16$ A, so:
$V_6=5\Omega*16A=80$ V, so
$V_5=96-80V=16V=V_1=V_{24}=V_3$;
voltage drop through caps=0

$t \rightarrow$infty: capacitor blocks current flow in all segments containing that resistor, so each of those segments are (effectively) infinite resistance branches, so to calculate R_{tot}, only include R_6, R_{24} and R_3, $R_{24}||R_3$; R_{234} in series with R_6, so $R_{234}=6\Omega$, $R_{tot}=11\Omega$,
$I_{tot}=8.73$ A;
$V_6=8.73A*5\Omega=43.63$ V, so
$V_{24}=V_3=96V-43.63V=52.37V$;
This is also the voltage drop across both C_1 and C_2, so
$Q_1=104.74C$ and $Q_2=209.48C$





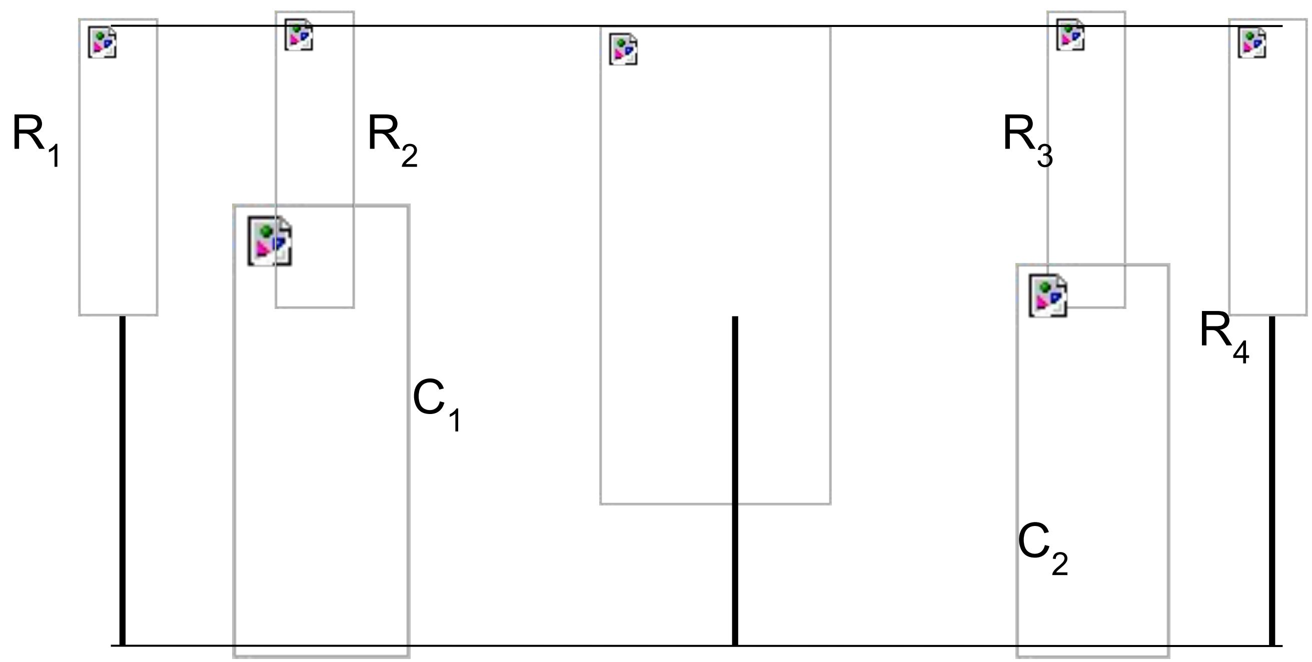
Find voltages at a and b, as well as voltage drops through all resistors in circuit.

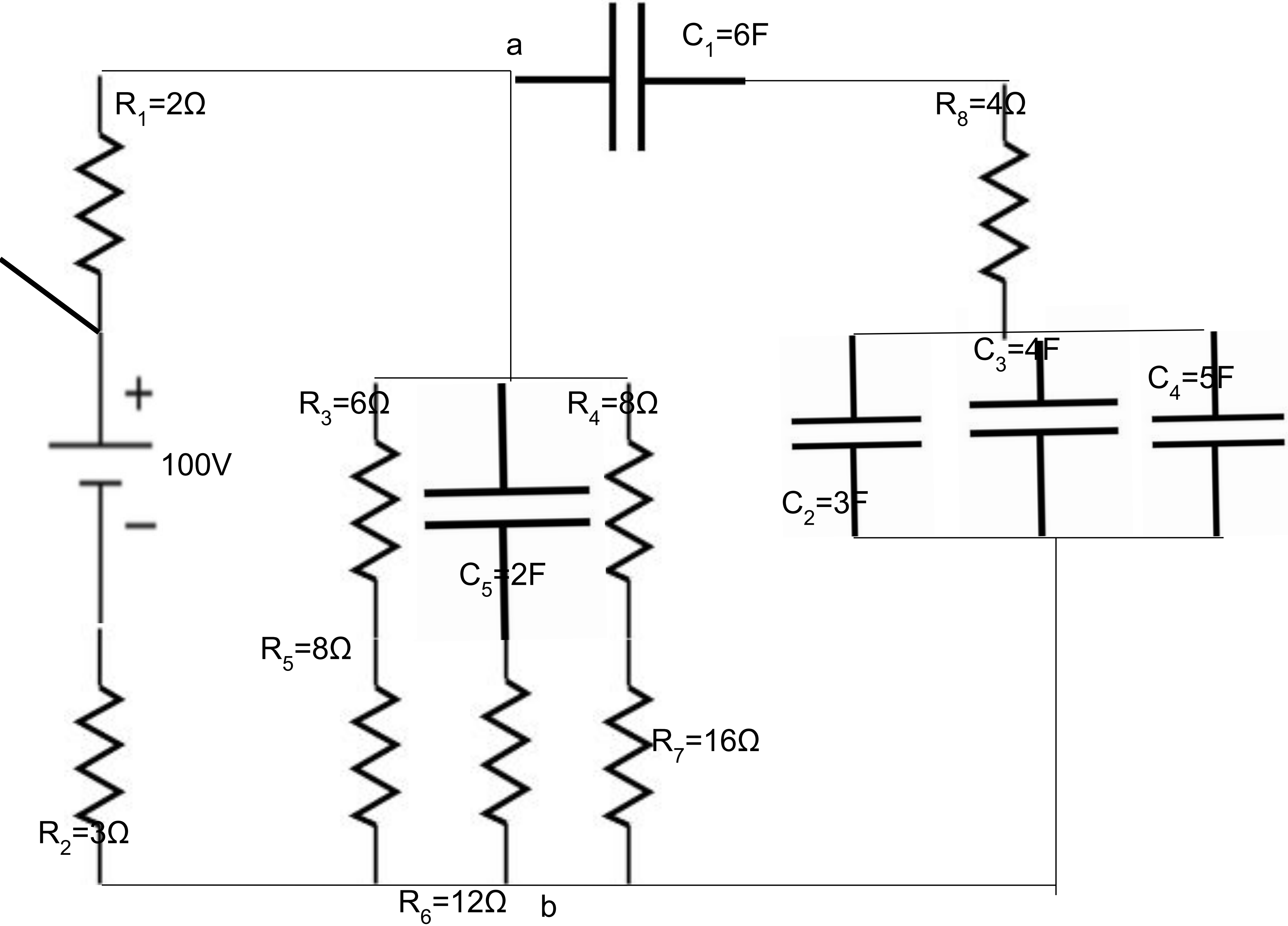
Repeat exercise for case where resistors are replaced by equivalent capacitors (e.g., 1Ω → 1F capacitor, etc. In that case, again find the voltage at points a and b, and also the charges on all the capacitors in the circuit.

In the circuit below, determine I_{tot} and also I_2 and Q_1 at $t=0$ and as $t\rightarrow$infty. $R_1=4\Omega$, $R_2=12\Omega$, $R_3=9\Omega$, $R_4=18\Omega$, $C_1=2F$, $V=36V$, $C_2=1F$

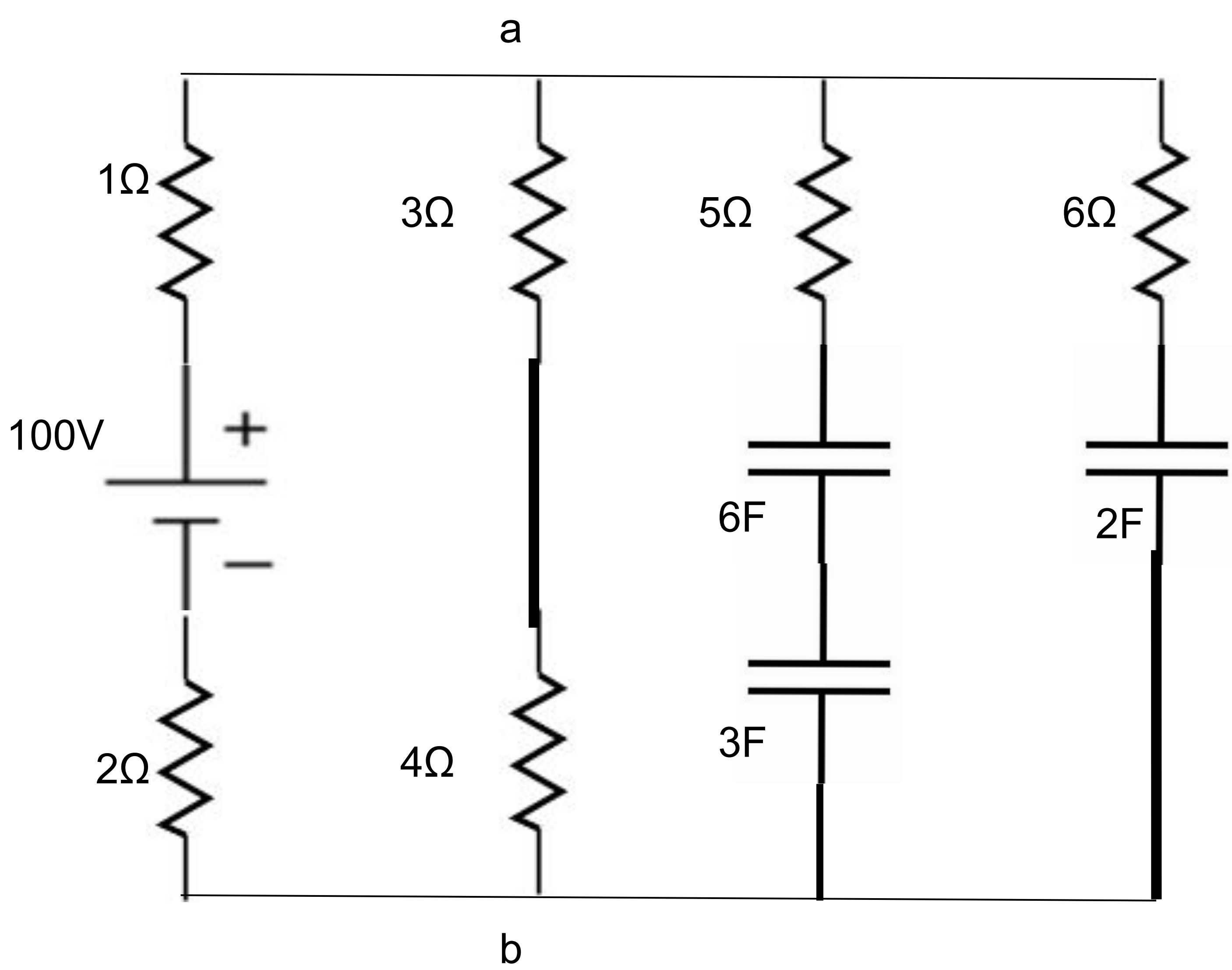
T=0: (I_{tot},I_2)=
A) 18A, 18A
B) 3A, 3A
C) 18A, 3A
D) 3A, 18A
E) NOTA

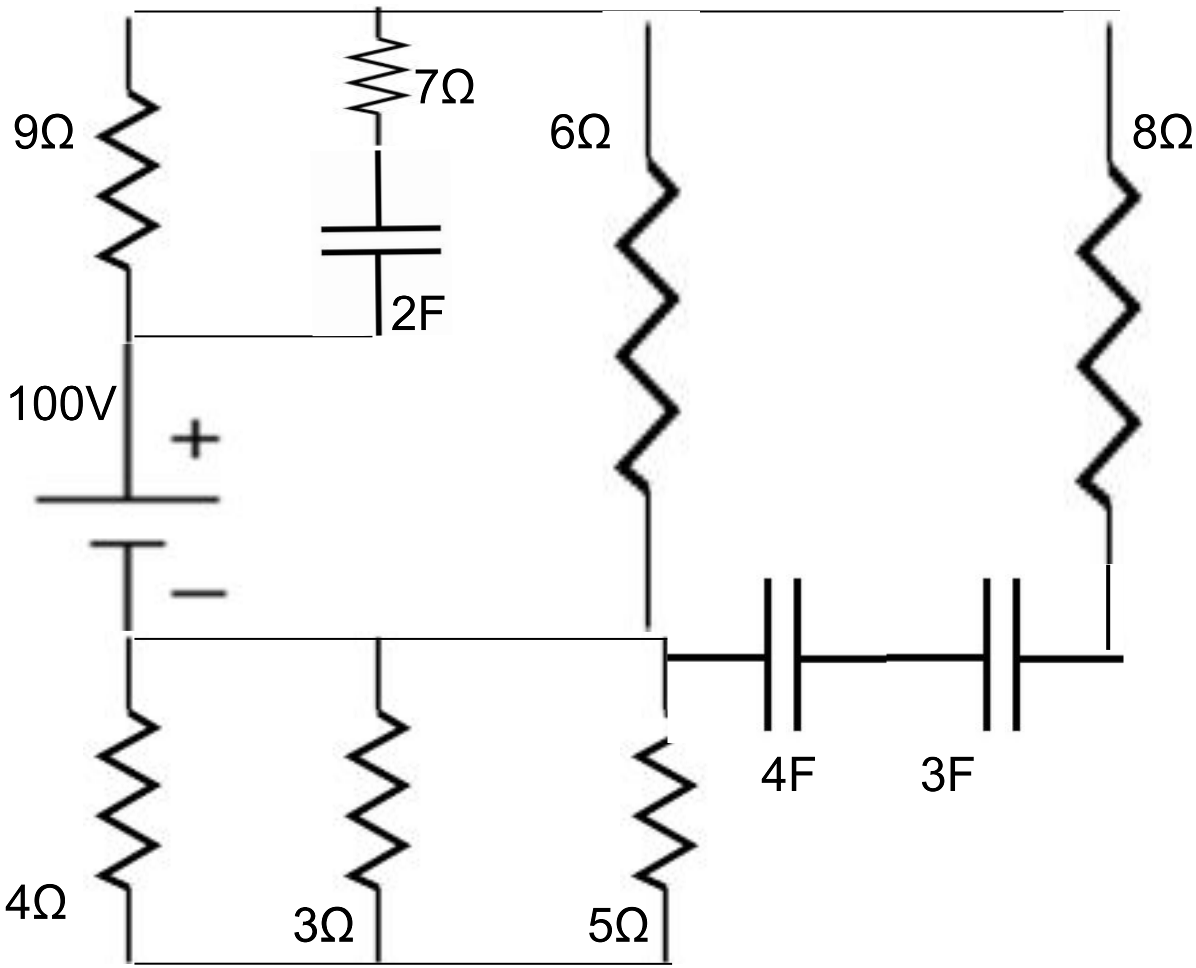
T$\rightarrow$infty: (I_{tot},C_1)=
A) 11A, 36C
B) 11A, 72C
C) 18A, 36C
D) 18A, 72C
E) NOTA





a
C1=6F
R1=2Ω
R8=4Ω
C3=4F
C4=5F
+
100V
-
R3=6Ω
R4=8Ω
C2=3F
C5=2F
R5=8Ω
R7=16Ω
R2=3Ω
R6=12Ω
b


a
1Ω
3Ω
5Ω
6Ω
100V
+
−
6F
2F
2Ω
4Ω
3F
b



9Ω
7Ω
2F
6Ω
8Ω
100V
+
−
4F
3F
4Ω
3Ω
5Ω

$R_1=R_2=R_3=R_4=10\Omega$; what is the charge on the capacitor as t→infty?

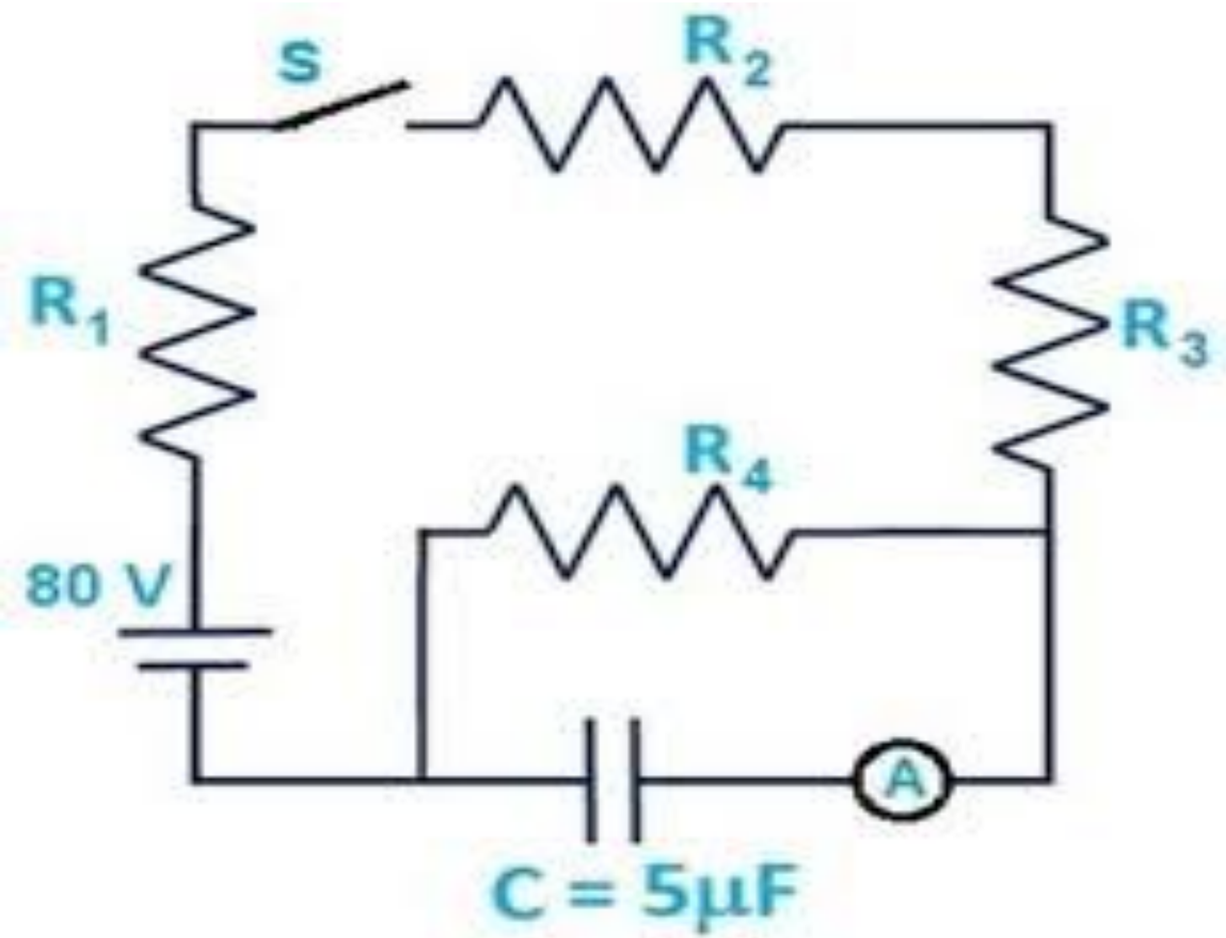
A) 20 μC

B) 40 μC

C) 80 μC

D) 100 μC

E) NOTA



Power dissipated in resistors and energy stored on capacitors=...

Power stored in electric field in capacitors=$Q^2/2C$
Heat lost as current flows through resistor=I^2R

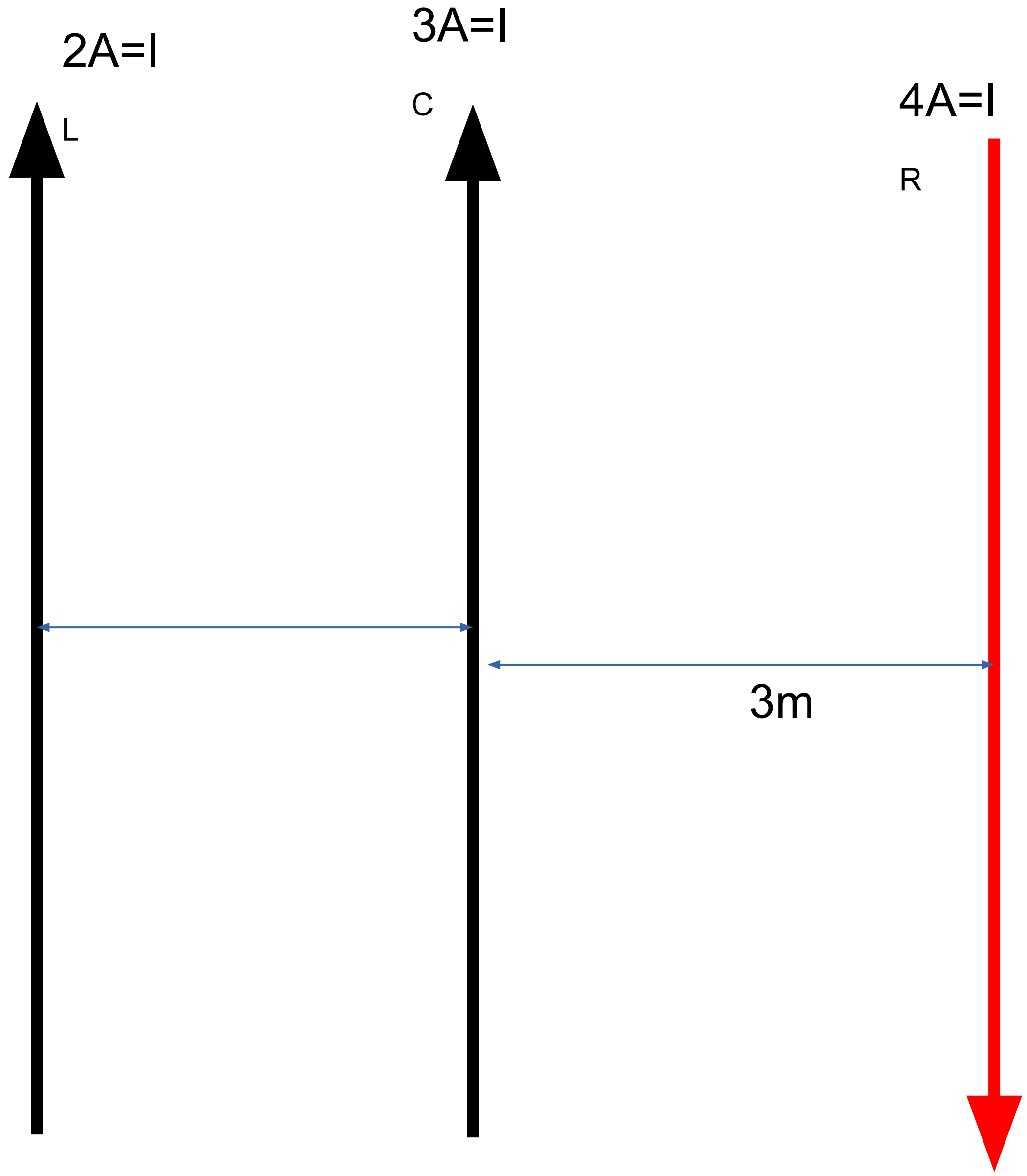
Not for all the tea in china...

F=q**v x B**

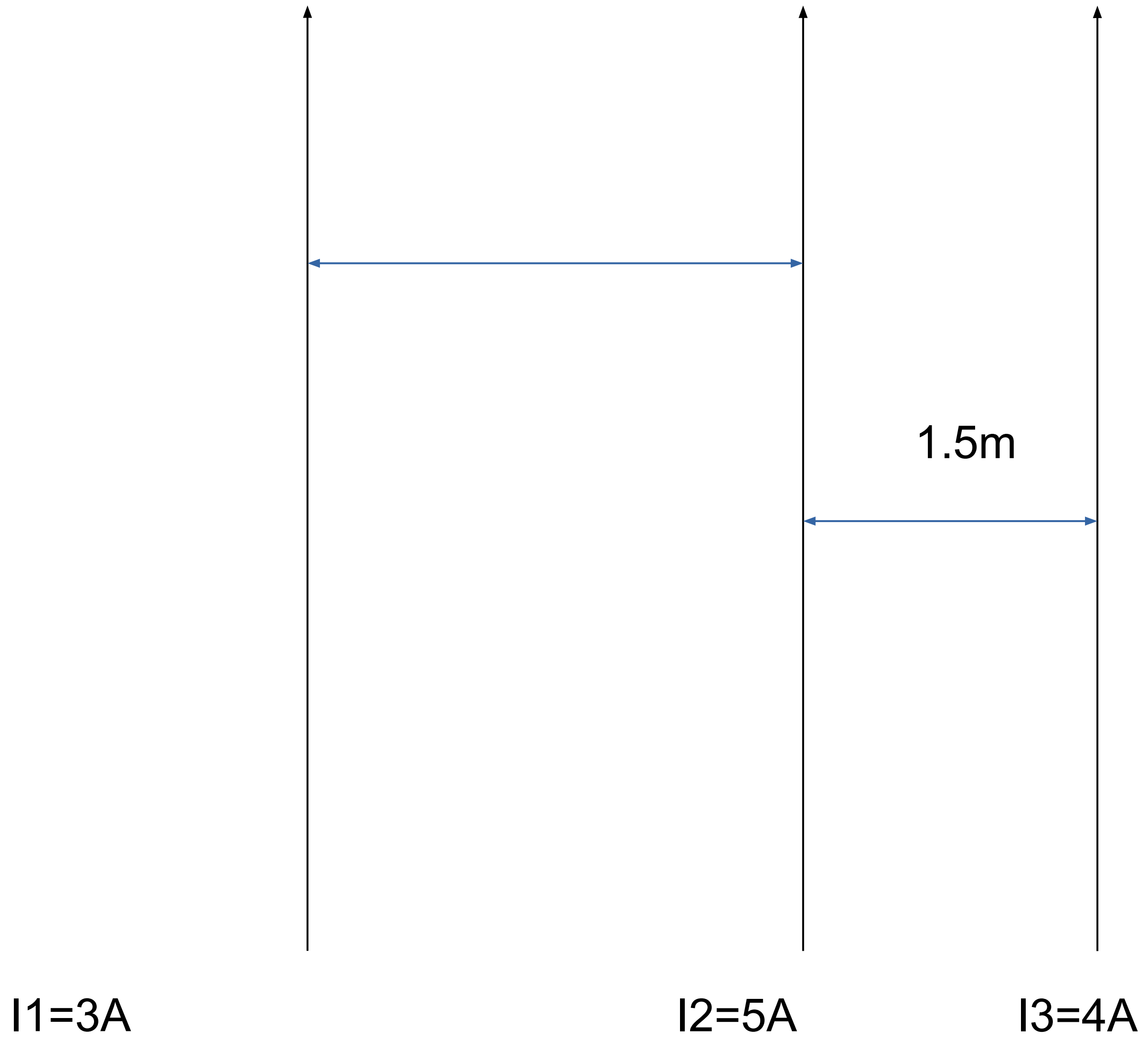
$B_{wire}=\mu_0 I/(2\pi r)$ (Ampere's Law); $\mu_0=4\pi \times 10^{-7}$, => $B=k'I/r$, with $k'=2 \times 10^{-7}$ T-m/A; two right-hand rules: (2) for direction of field *(magnetic field lines are tangents to circles centered on given current; i.e., B is at 90^o to line joining current and measurement point P)*, and (1) for direction of Force.

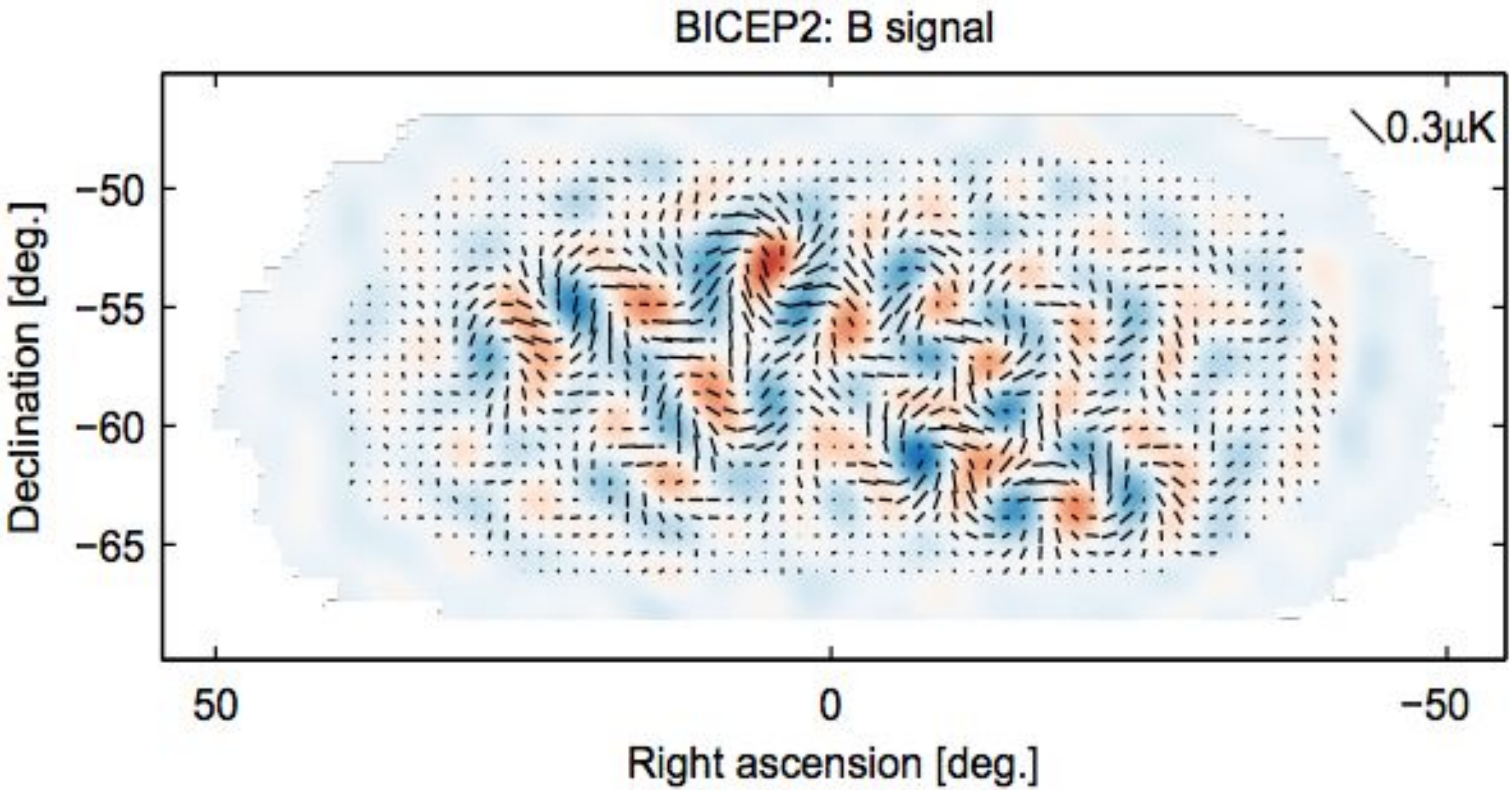
$B_{loop}=\mu_0 I/(2r)=\pi k'I/r$

$EMF=-\Delta\Phi/dt$



2A=I
L
3A=I
C
4A=I
R
3m

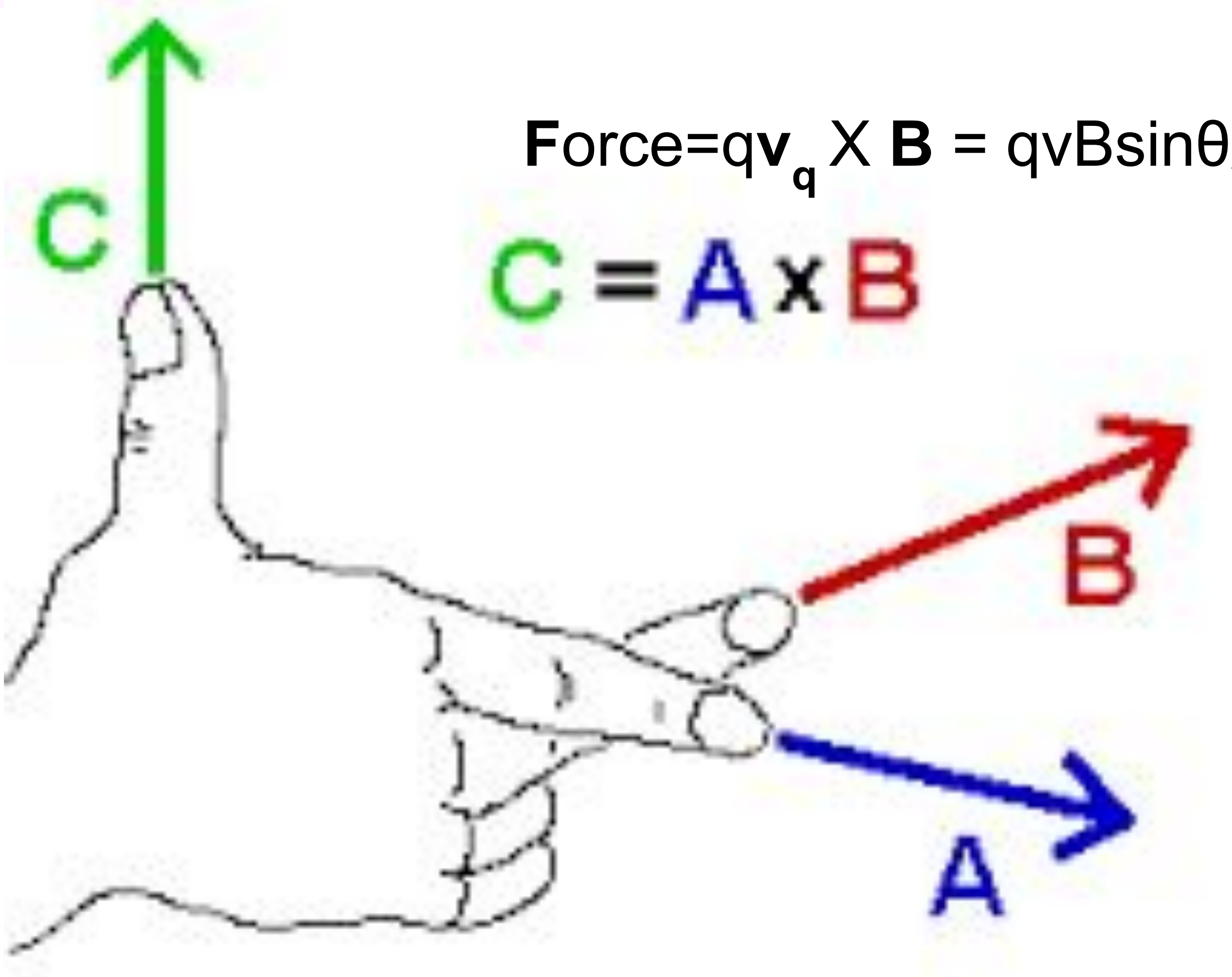

1.5m
I1=3A
I2=5A
I3=4A



BICEP2: B signal
0.3μK
Declination [deg.]
−50
−55
−60
−65
50
0
−50
Right ascension [deg.]

“Force” RHR(1)

$\mathbf{F}orce = q\mathbf{v}_{\mathbf{q}} \times \mathbf{B} = qvB\sin\theta_{v,B}$



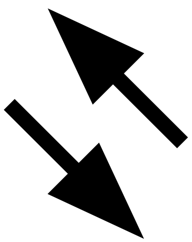
A magnetic field B_z=+1 T (out-of-page) fills the region below. The direction of deflection of an electron moving as shown would be:

A) +z

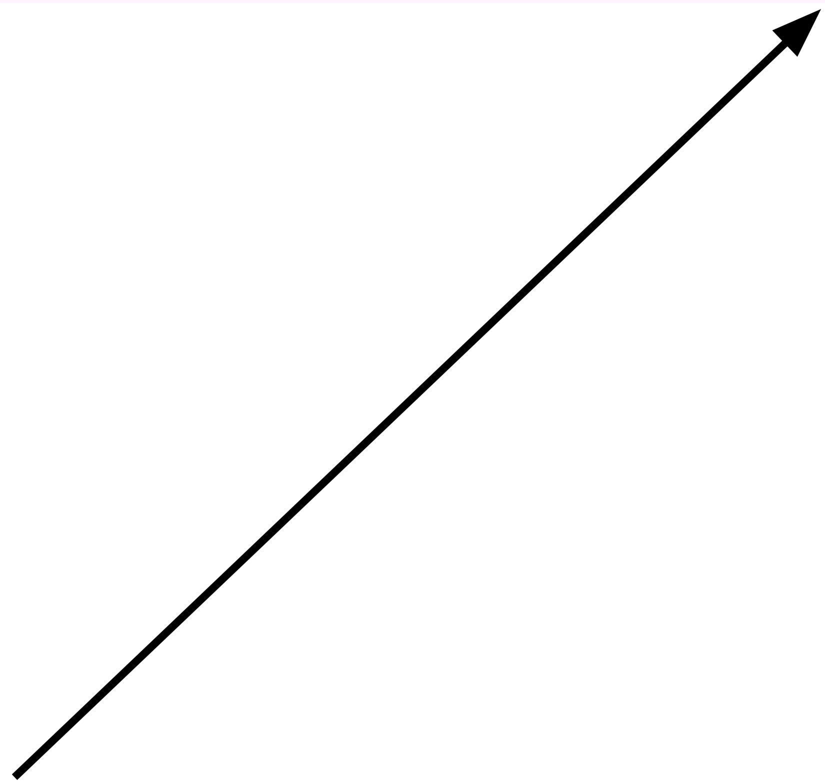
B) -z

C)

D)



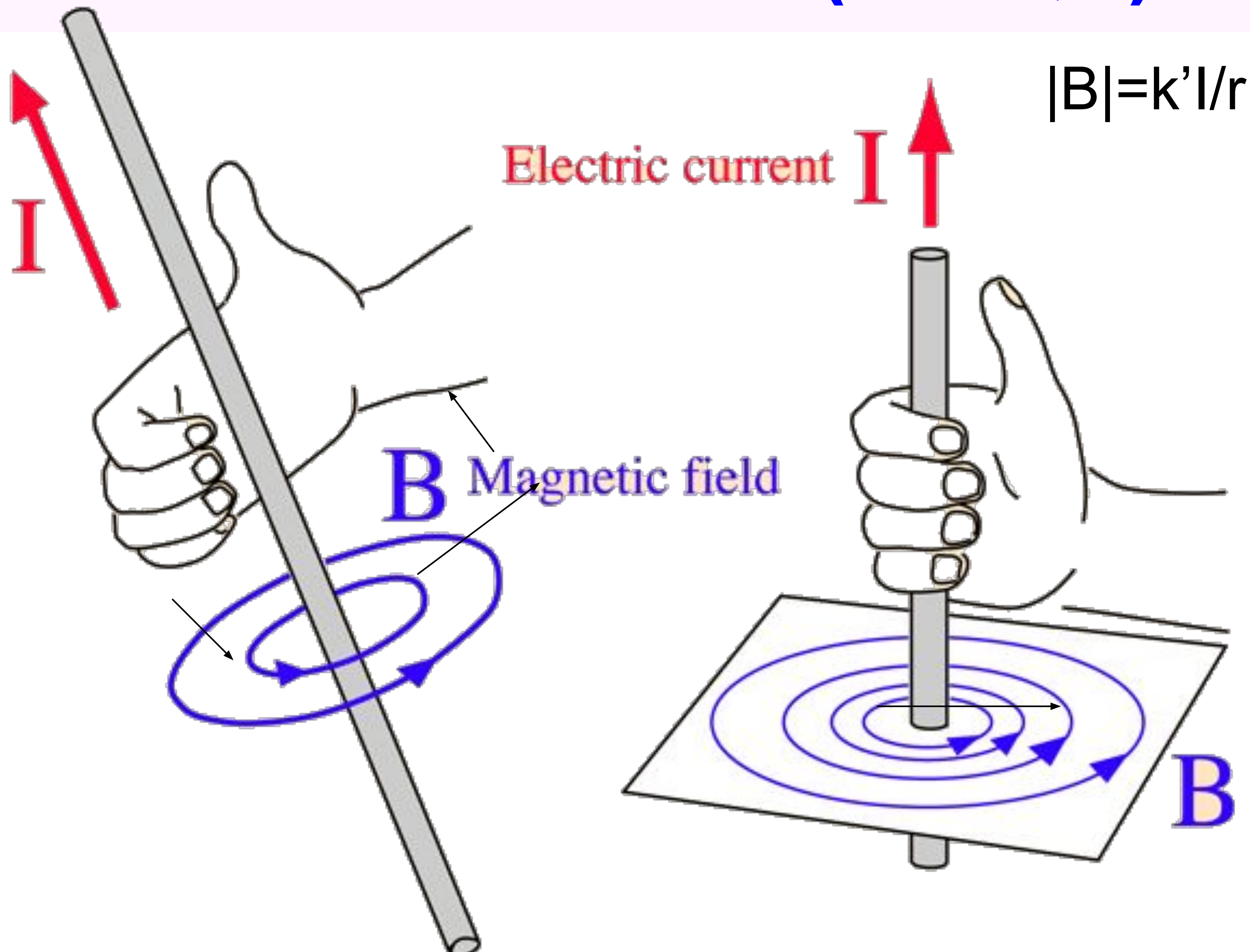
E) NOTA



e^-

B-field direction (RHR,2)

$|B|=k'I/r$

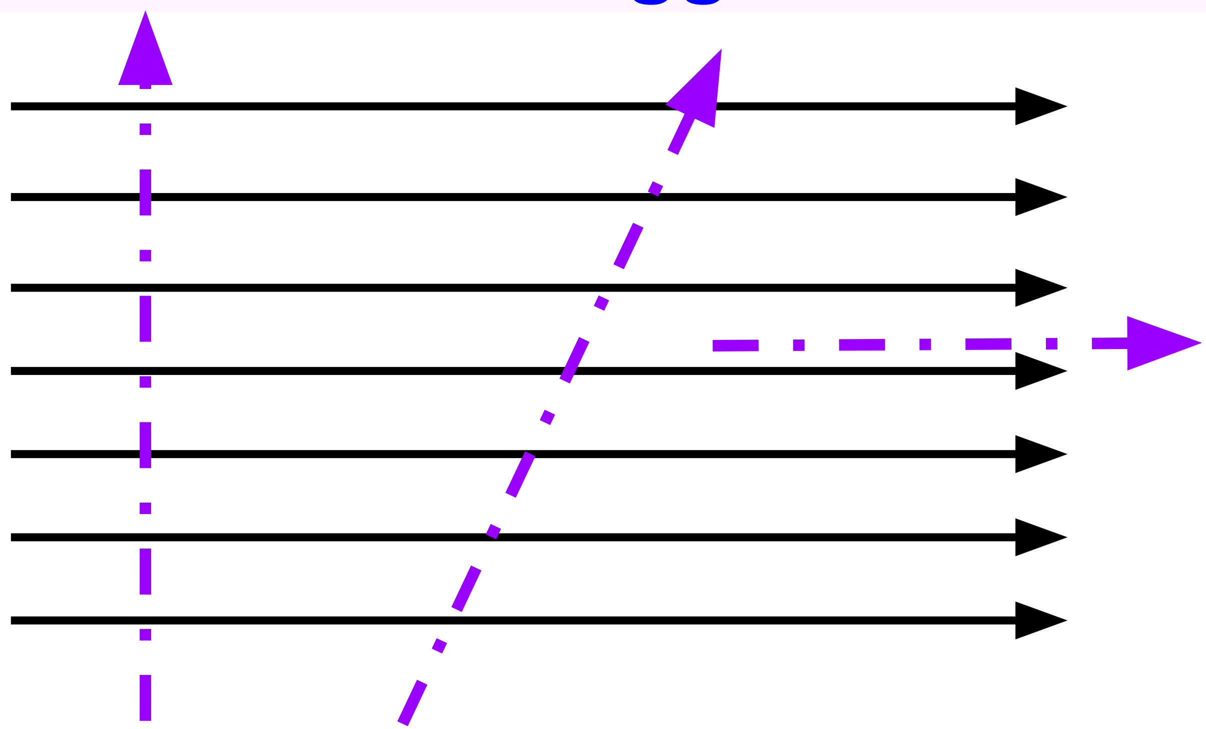


Three protons move with v=1 m/s, 1.2 m/s (at an angle of 30° wrt vertical) and 2 m/s (left-to-right). Which proton experiences the biggest deflection?

A) (left)

B) (center)

C) (right)



A current I flows as shown. The deflection of the moving electron is:

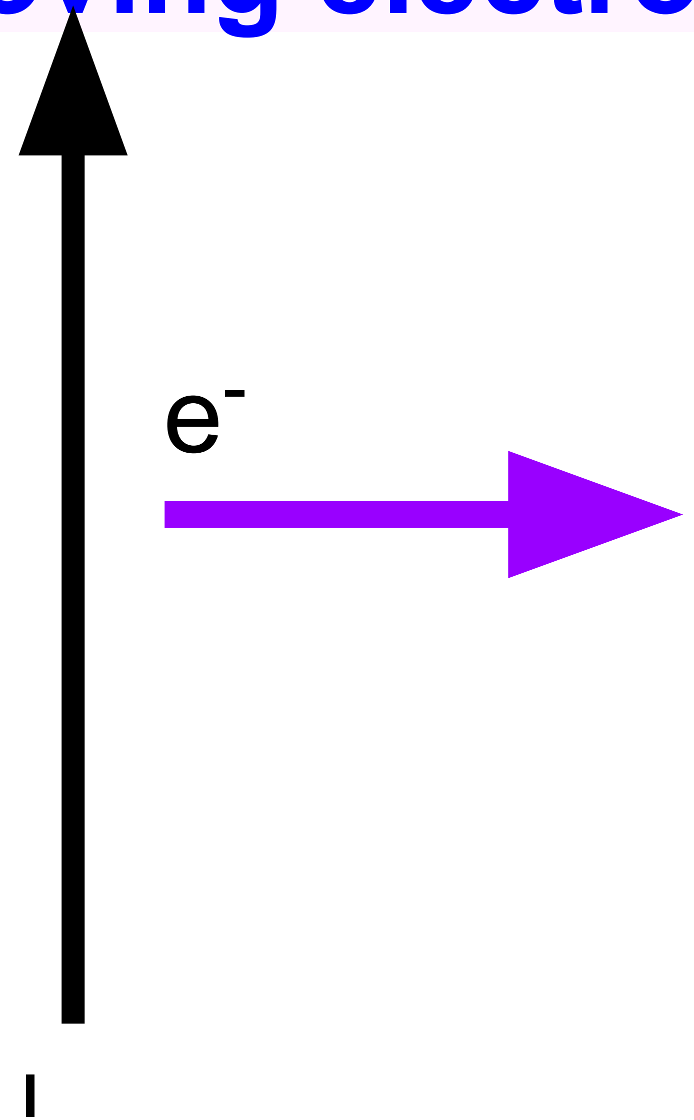
A) Up

B) Down

C) +z (out-of-page)

D) -z (into page)

E) NOTA

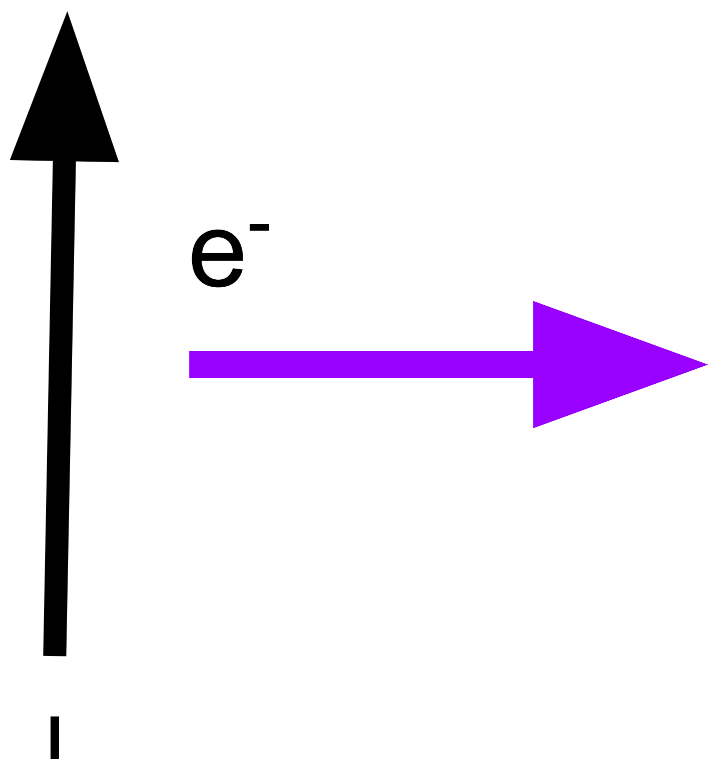


As the electron moves, it must (recall the definition of $W=|F||d|\cos\theta_{F,d}$)

A) move faster

B) move slower

C) Move with constant velocity



A current of 4 amps flows through a wire in the +y-direction. A particle with charge -2 Coulombs and mass 4 kg at the point **x=2 m** moves with velocity v making an angle of 60^o relative to the wire, with a magnitude of $3x10^6$ m/s. What is the magnetic field vector at the location of the charge?

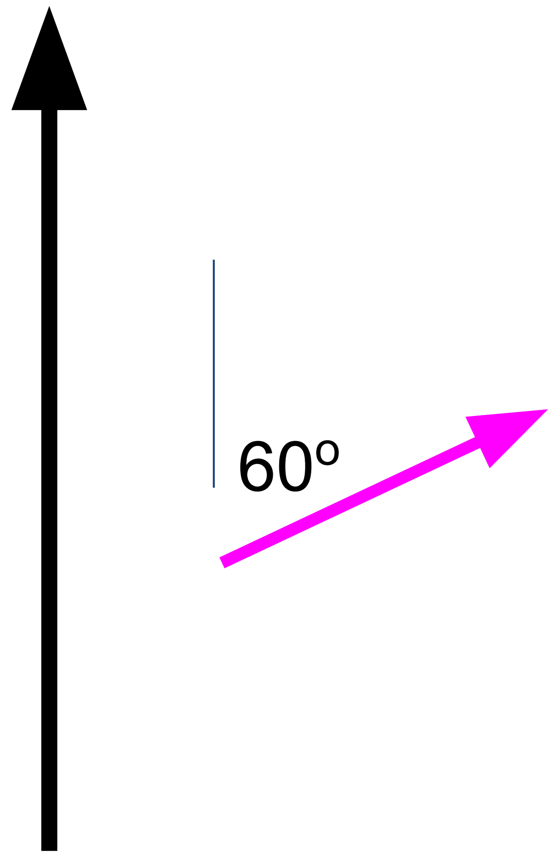
A) 4×10^{-7} T, -z (into page)

B) 4×10^{-7} T, +z (out of page)

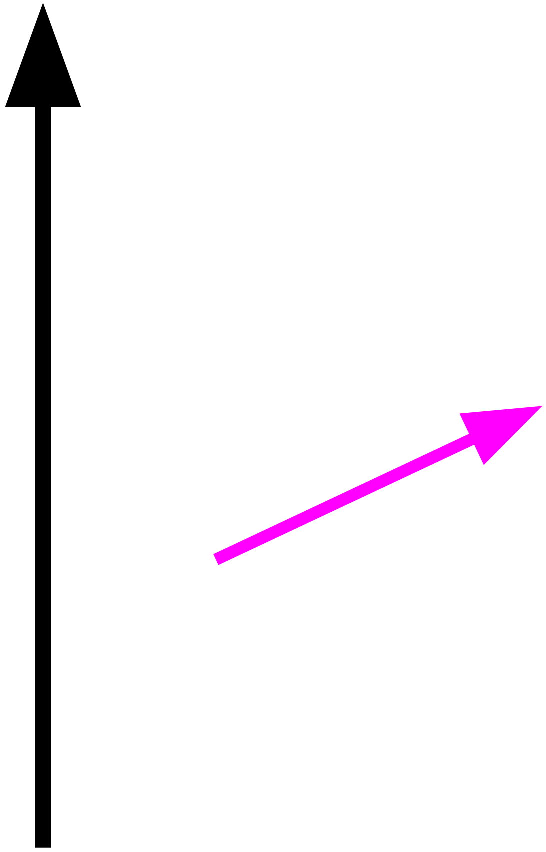
C) 10^{-7} T, -z (into page)

D) 10^{-7} T, +z (into page)

E) NOTA



A current of 4 amps flows through a wire in the +y-direction. A particle with charge -2 Coulombs and mass 4 kg at the point x=2 m moves with velocity v making an angle of 60^{o} relative to the wire, with a magnitude of $3x10^{6}$ m/s. What is the Force at the location of the charge?



A) 2.4 N, $+120^{o}$ wrt +x

B) 2.4 N, -60^{o} wrt +x

C) 1.2 N, +z

D) 1.2 N, -z

E) NOTA

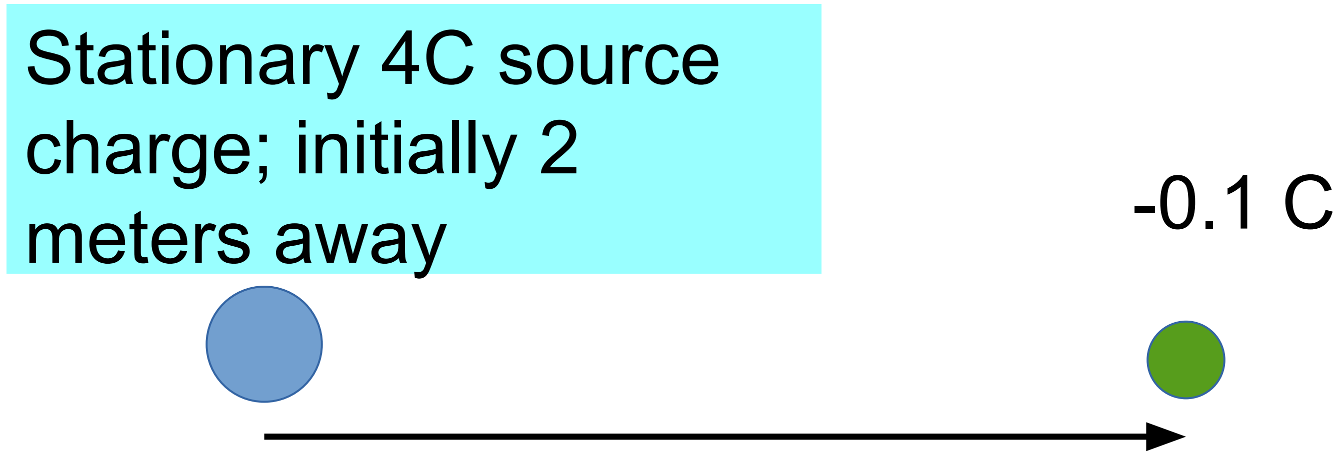
A) 9 x 10^{-5} A

B) 9 milliAmps

C) 4.5 Amps

D) 4.5 milliAmps

E) NOTA



After 0.2 ns, the current constituted by the moving 2 kg, -0.1 C charge is about:

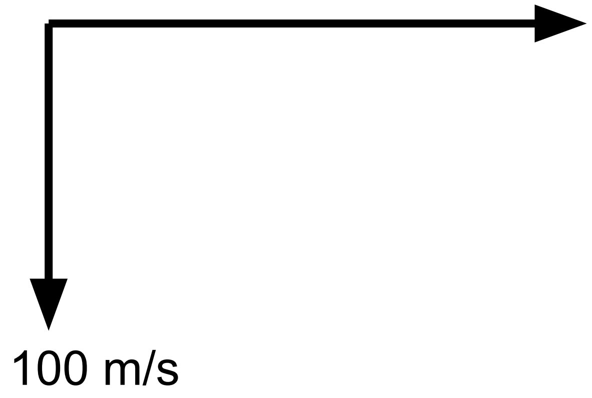
A 2 kg, -3C charge moving at v_y=-100 m/s enters a magnetic field region with B_x=+4T. The magnitude of the acceleration of the mass is:

A) Approximately equal to g

B) About 60X greater than g

C) About 60X less than g

D) About 6000x less than g



An uncharged wire, containing free electrons, moves in the +x-direction, in a region with a magnetic field in the +z-direction. In which direction do the electrons move?

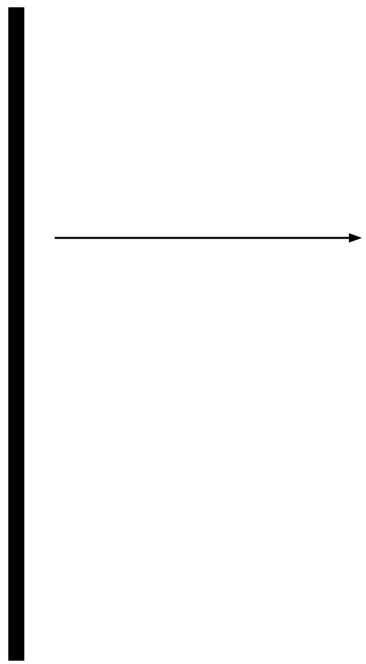
A) Up

B) Down

C) Left

D) Right

E) NOTA



In which direction is the center e^- deflected?

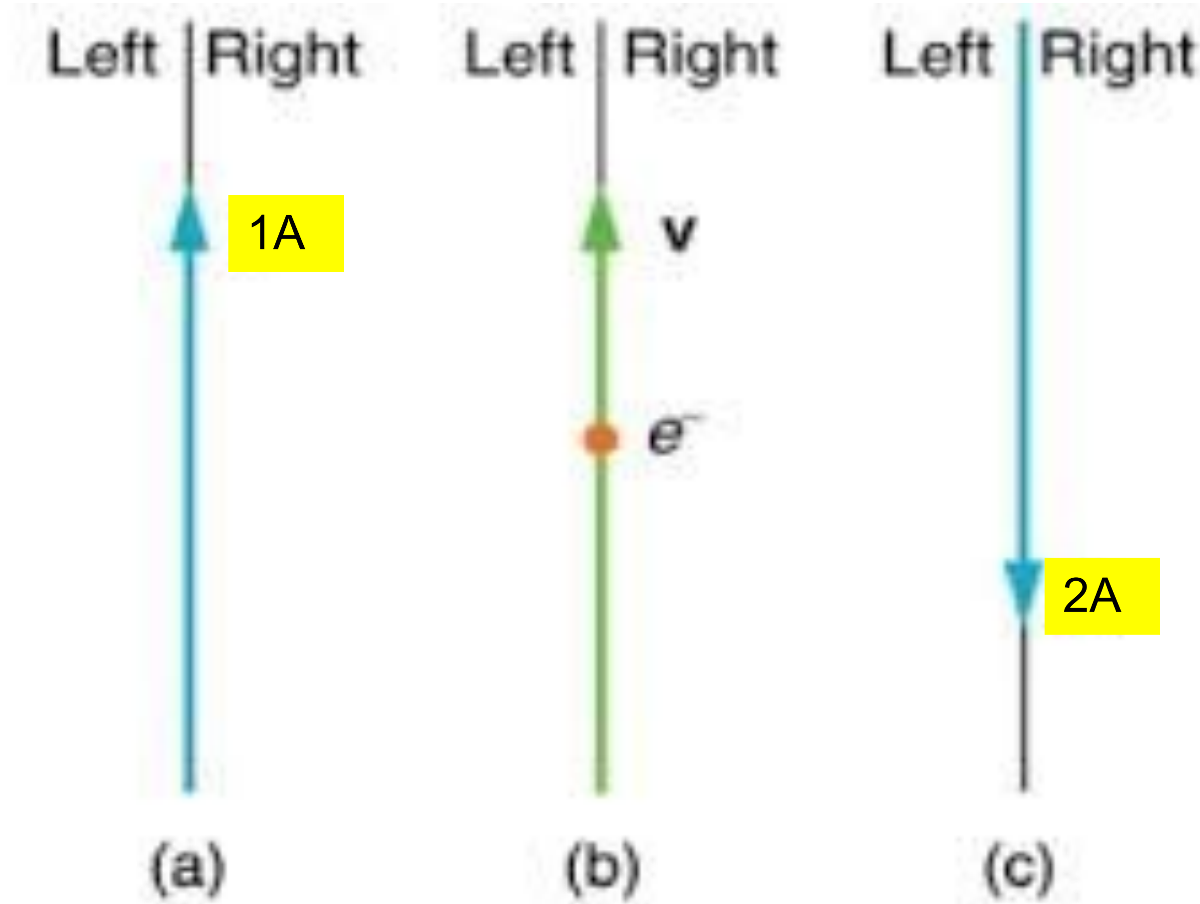
A) Left

B) Right

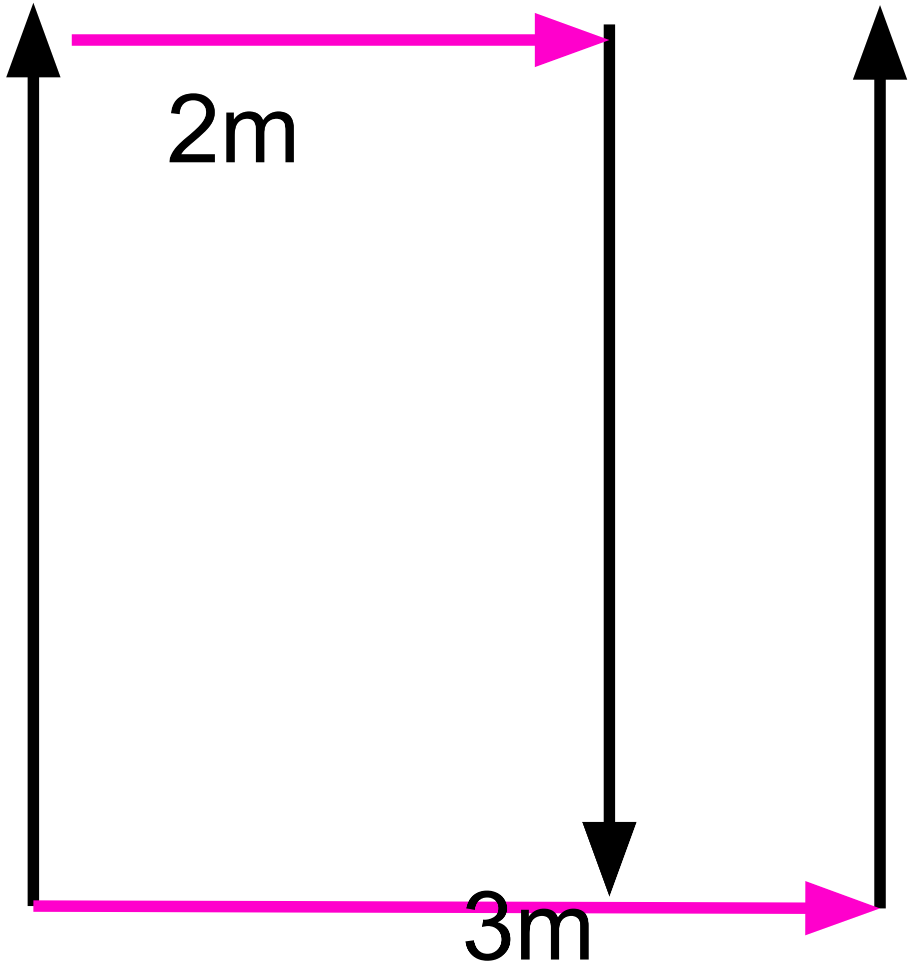
C) +z

D) -z

E) NOTA



B_{net} at the location of the left wire (I_{Left}=1A; I_{Center}=3A; I_{Right}=4A) is:



A) 0.17k' (+z)

B) 0.17k' (-z)

C) 2.83k' (+z)

D) 2.83k' (-z)

E) NOTA

The directions of B_{net} at the locations of the 3 wires (I_{Left}=1A; I_{Center}=3A; I_{Right}=4A) are:

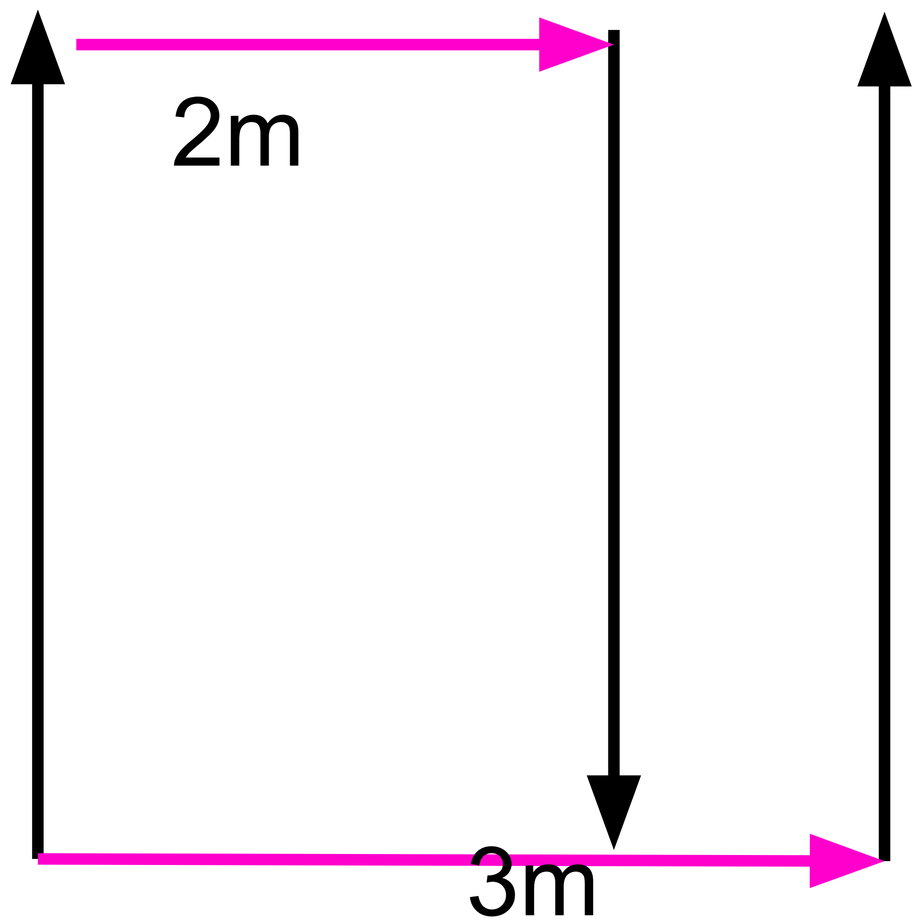
A) -z,+z,+z

B) +z,-z,+z

C) +z,+z,-z

D) -z,-z,+z

E) NOTA



The deflections of the 3 wires (I_{Left}=1A; I_{Center}=3A; I_{Right}=4A) are:

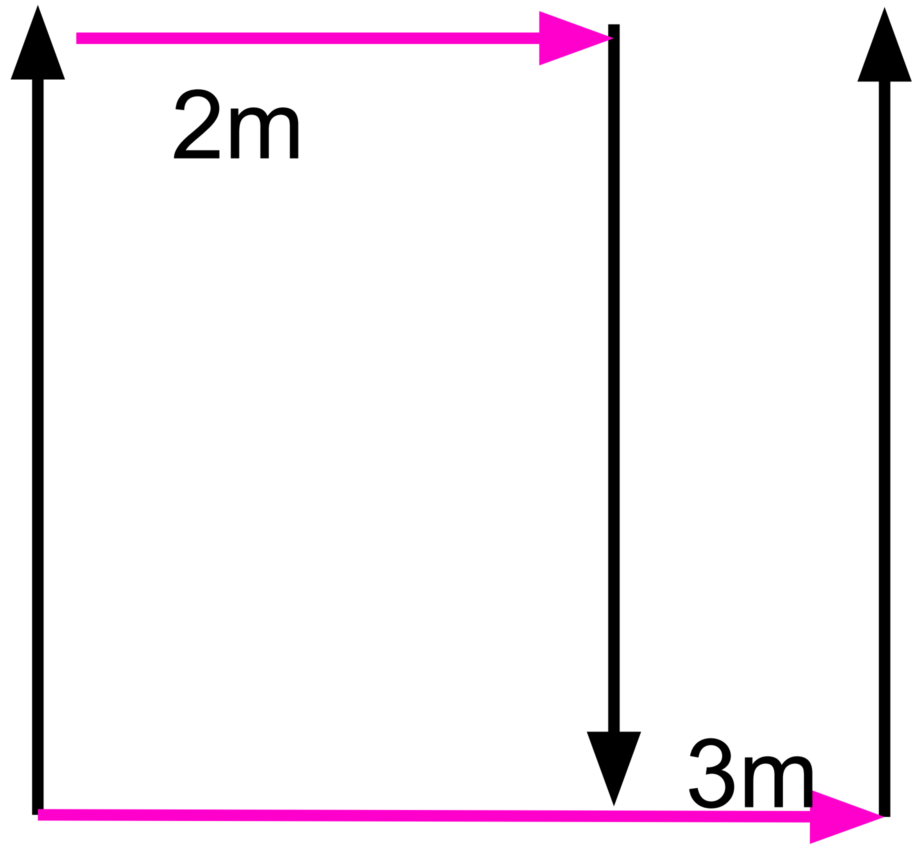
A) 0, L, R

B) L, L, R

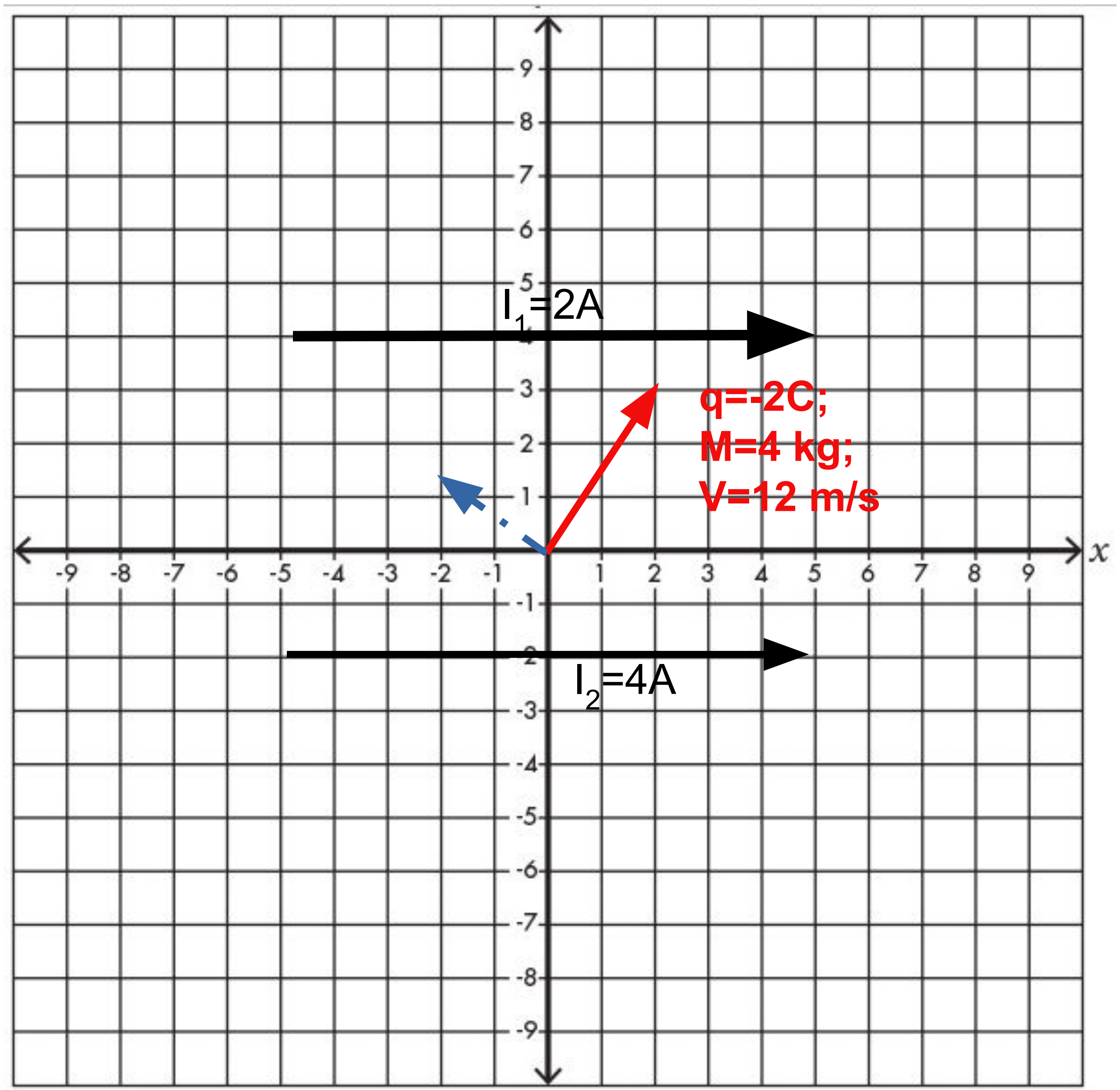
C) L, 0, R

D) R, L, 0

E) NOTA

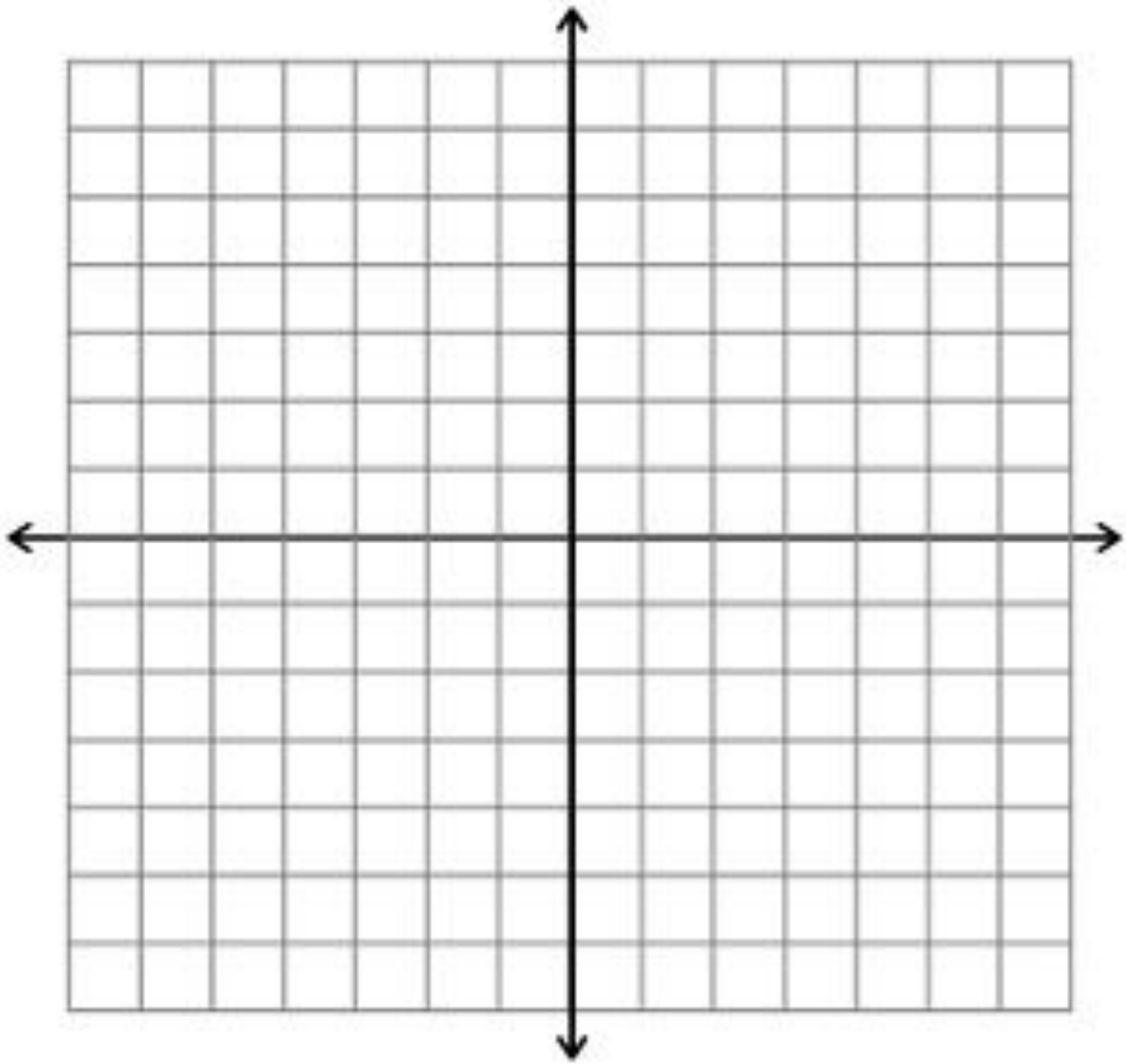


Want to find a) net magnetic field (via RHR-2) due to source currents, and then b) magnetic force (via RHR-1) on **q** at origin



a) Add magnetic fields from two wires: from top wire, B_1=k'(2A)/4m in -z direction (into page); bottom wire: B_2=k'(4A)/2m in +z-direction (out-of-page), so net field=1.5k' Tesla in +z

b) magnetic force on **-2C** charge given by F_B=qvBsinθ, with θ the angle between B and the velocity. In this case, 90° since B=B_z and velocity in xy-plane. So, find magnitude and direction in case where q is positive, then invert (since q actually negative). $|F_B|$=2*12*1.5k'sin(90)=7.2e-6=ma, so acceleration=1.8e-6 m/s^2 Direction as shown by blue arrow, since charge is negative

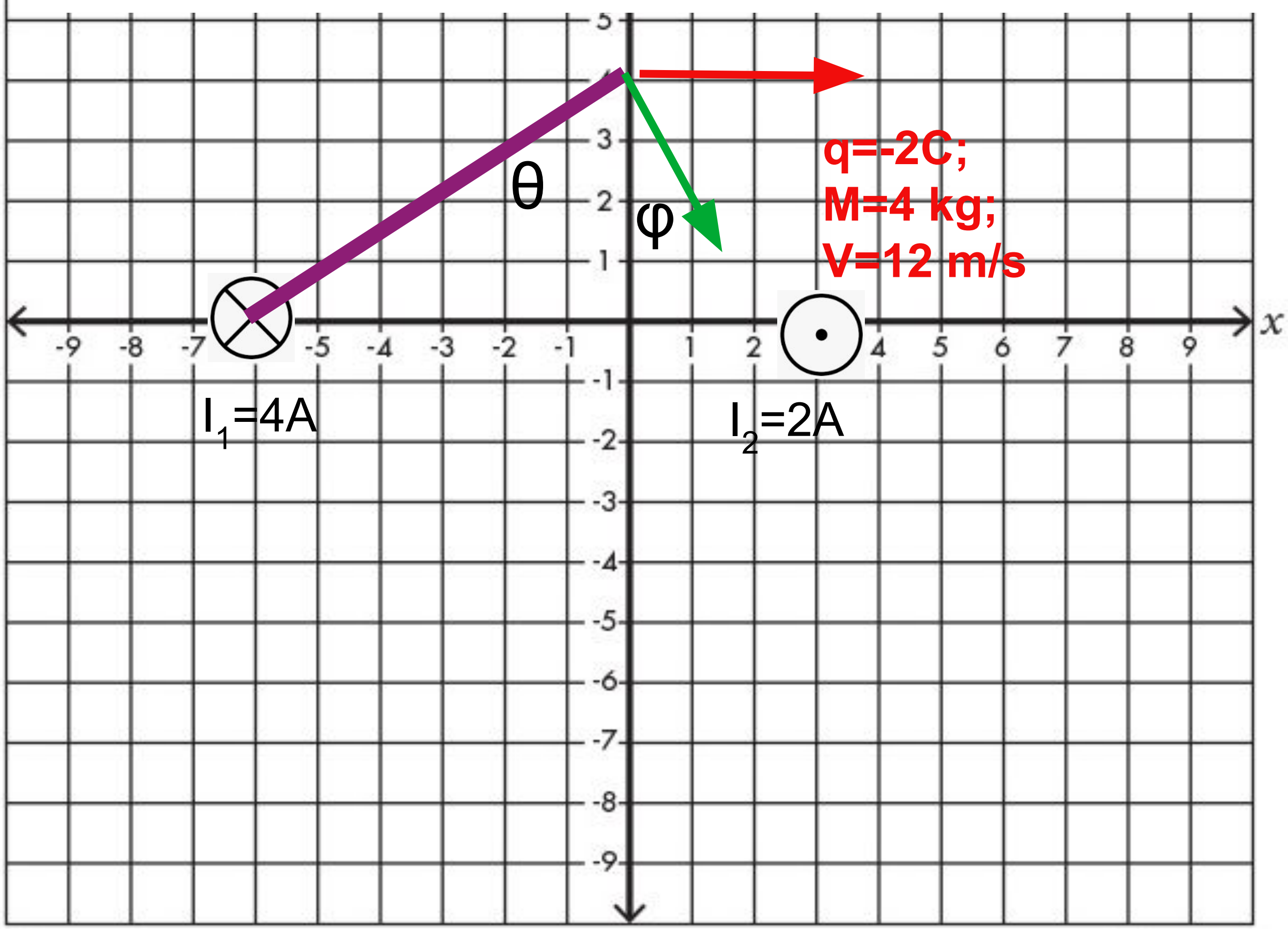


Want to find a) net magnetic field (via RHR-2) due to source currents, and then b) magnetic force (via RHR-1) on **q** at (0,4) a) Add magnetic fields from two wires: from top wire, B_1=k'(4A)/r1; r1=sqrt(36+16)=sqrt(52). To get direction, draw line from source to measurement point - line is radius of circular magnetic field line. Tangent would be 90 degrees from that line. In diagram, θ is angle wrt y-axis, so tanθ=6/4, or θ=56.3°, B-field is at right angle wrt line, so φ=90-56.3=36.7° - since, in this case velocity is directly along x-axis, the angle b/w B and v is also 56.3°,

b) magnetic force on **-2C** charge, due to 1st source only, is given by F_B=qvBsinθ, with θ here=56.3°

So F=2C*12m/s*k'*4A/sqrt(52)*sin(56.3); k'=2×10^{-7}, so F=2.21×10^{-6} N; direction is into page!

Similarly, add force from 2A source…



The ratio B(X)/B(Y) is:

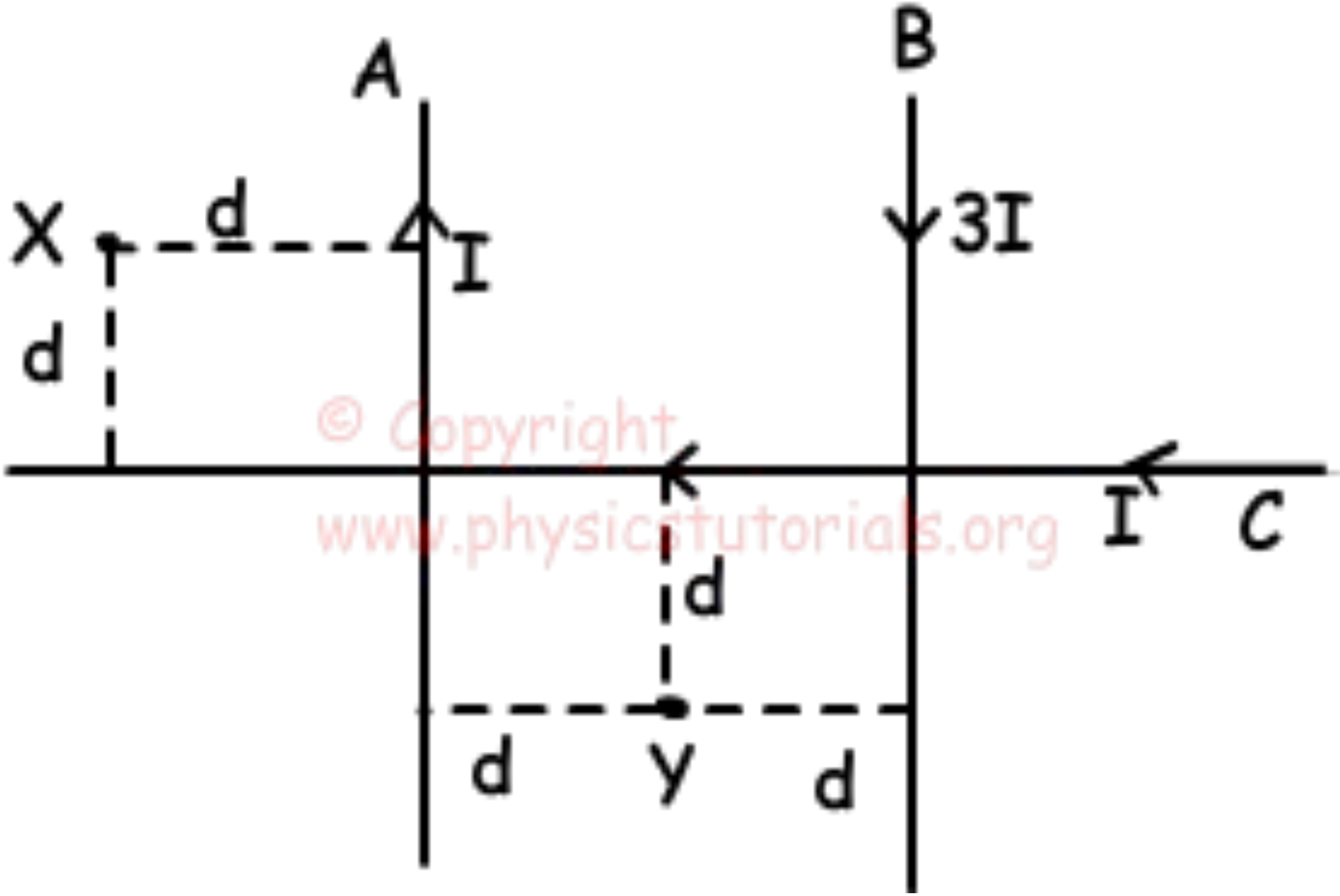
A) 1

B) 1/3

C) 3

D) 9

E) NOTA



An electron moves with initial velocity v. As time proceeds...

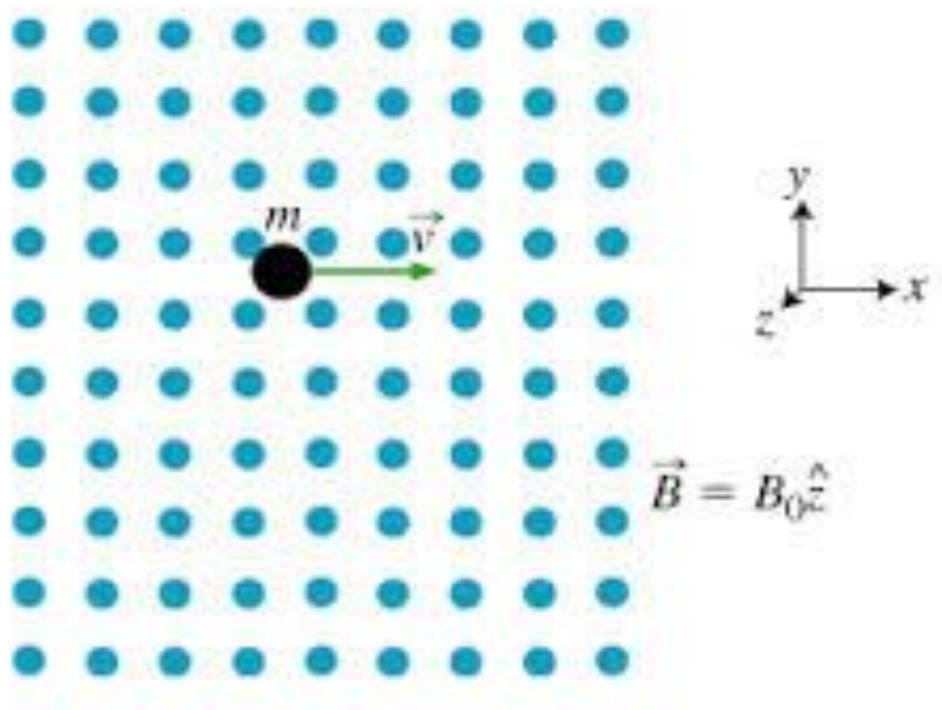
A) The e^- moves up, then continues straight

B) The e^- moves down, then continues straight.

C) The e^- moves up, then moves in a counter-clockwise circle

D) The e^- moves down, then follows a circular motion clockwise

E) NOTA



The charges of the particles shown are:

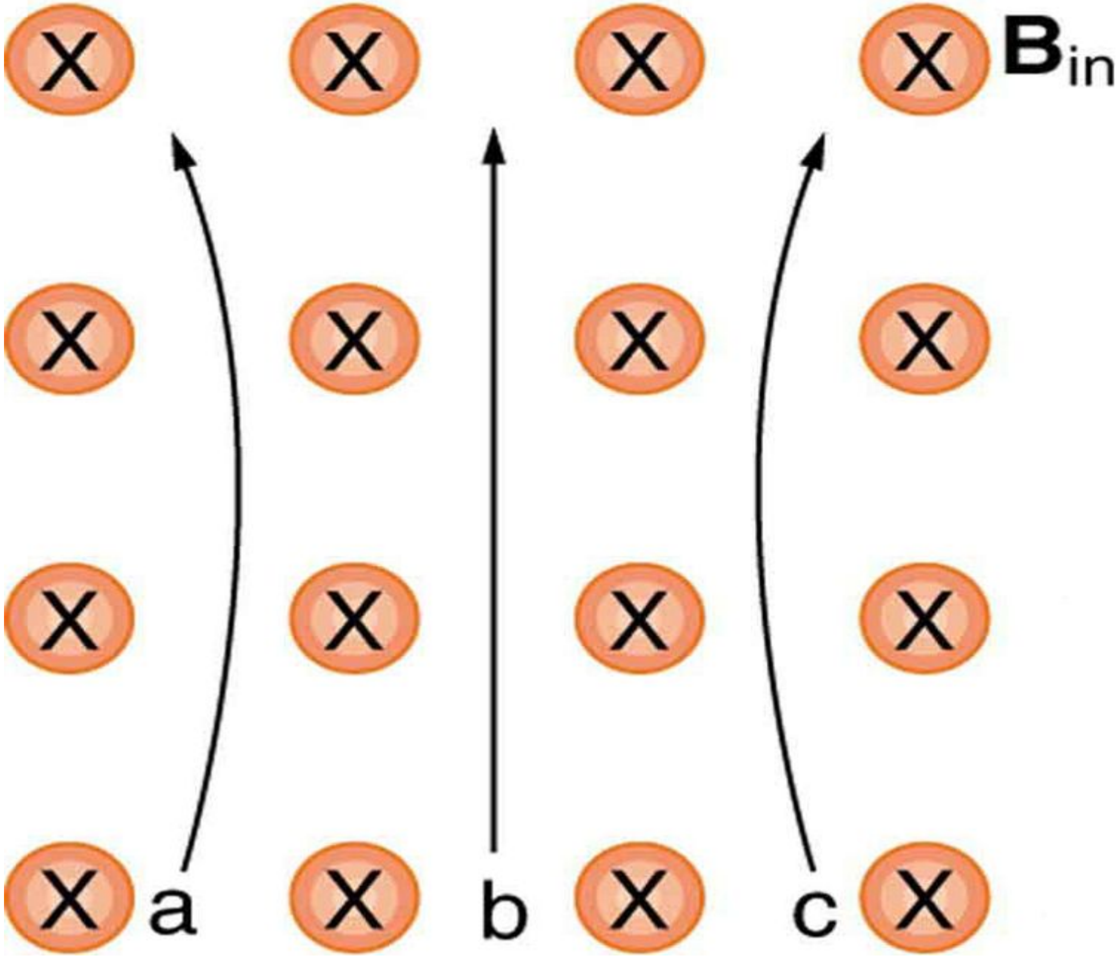
A) +, 0, -

B) -, 0, +

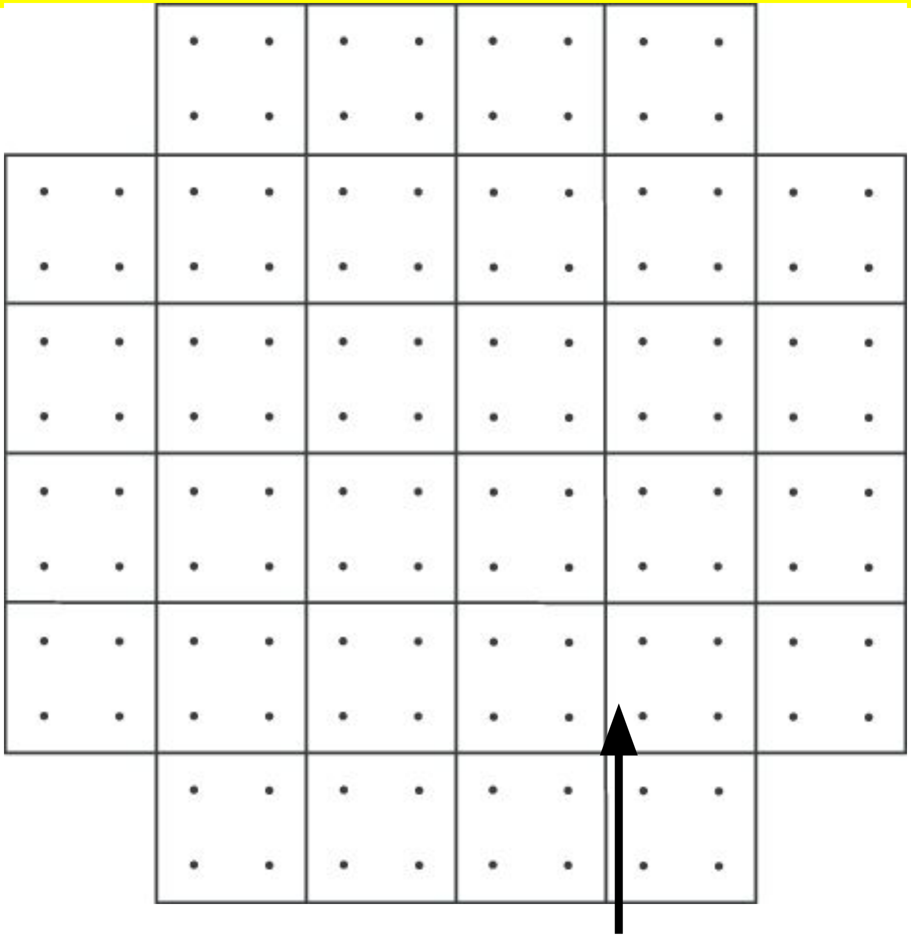
C) -, 0, -

D) +. 0, +

E) NOTA

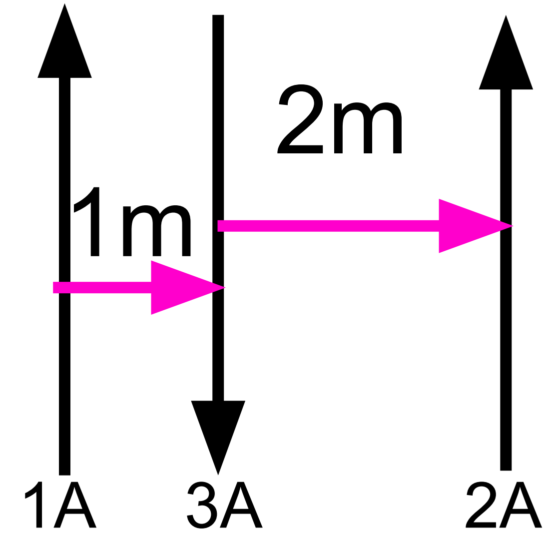


A particle of mass 2 kg and charge -2 Coulomb enters a magnetic field having magnitude 4 Tesla and direction +z. If it has an initial velocity 5 m/s in the +y-direction, the direction of its initial deflection is: A) +x B) -x C) +y D) -y E) NOTA



Assuming it is confined in the B-field, the radius of the particle's circular motion is:
A) 4 m B) 1.2 m C) 80 cm D) 40 cm E) NOTA

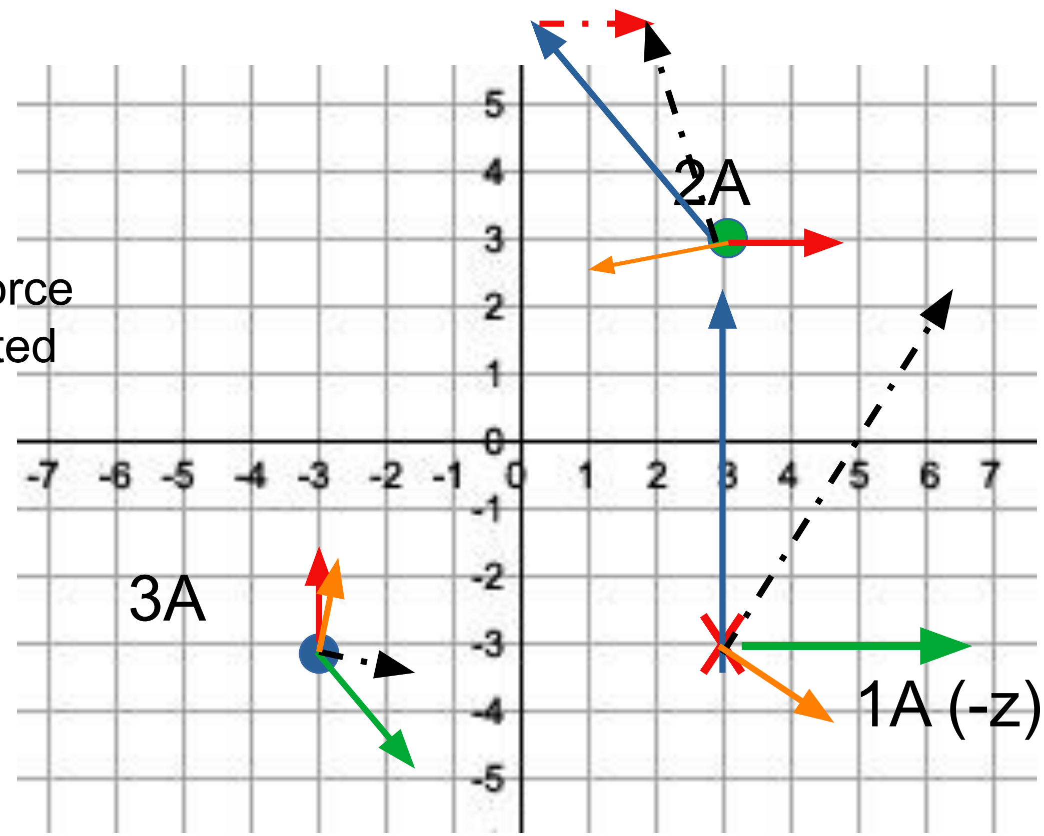
$B_{2,3}$(1A)=k'(3A/1m[-z]+2A/3m[+z])=7k'/3[-z]; -x deflection (R)
$B_{1,2}$(3A)=k'(1A/1m[-z]+2A/2m[+z])=0 (no deflection)
$B_{1,3}$(2A)=k'(1A/3m[-z]+3A/2m[+z])=7k'/6[+z]; +x deflection (R)



Orange arrow gives net deflection direction

Find B_{tot} at location of (2A) current:
B_{1A}(2A)=k'/6 (+x);
B_{3A}(2A)=3k'/8.48 (45^o wrt +y);
$B_{3A,x}$(2A)=-0.25k'; $B_{3A,y}$(2A)=+0.25k'; resultant indicated by black dashed arrow. Deflection force indicated by orange arrow (RHR-1). 2A attracted to 3A, and repelled from 1A.

B_{tot}(3A)=2k'/8.48 (-45^o wrt x)+k'/6(+y)
B_{tot}(1A)=2k'/6(+x) + 3k'/6 (+y)



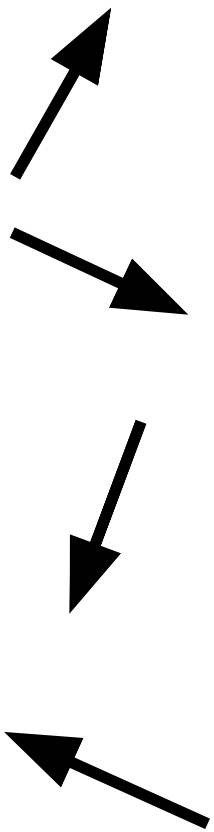
Given the current-carrying wires (2A in -z-direction at (0,0) and 5A in +z-direction at (3,0)) shown. B_{net} at (x,y)=(0,4) at P is in which direction?

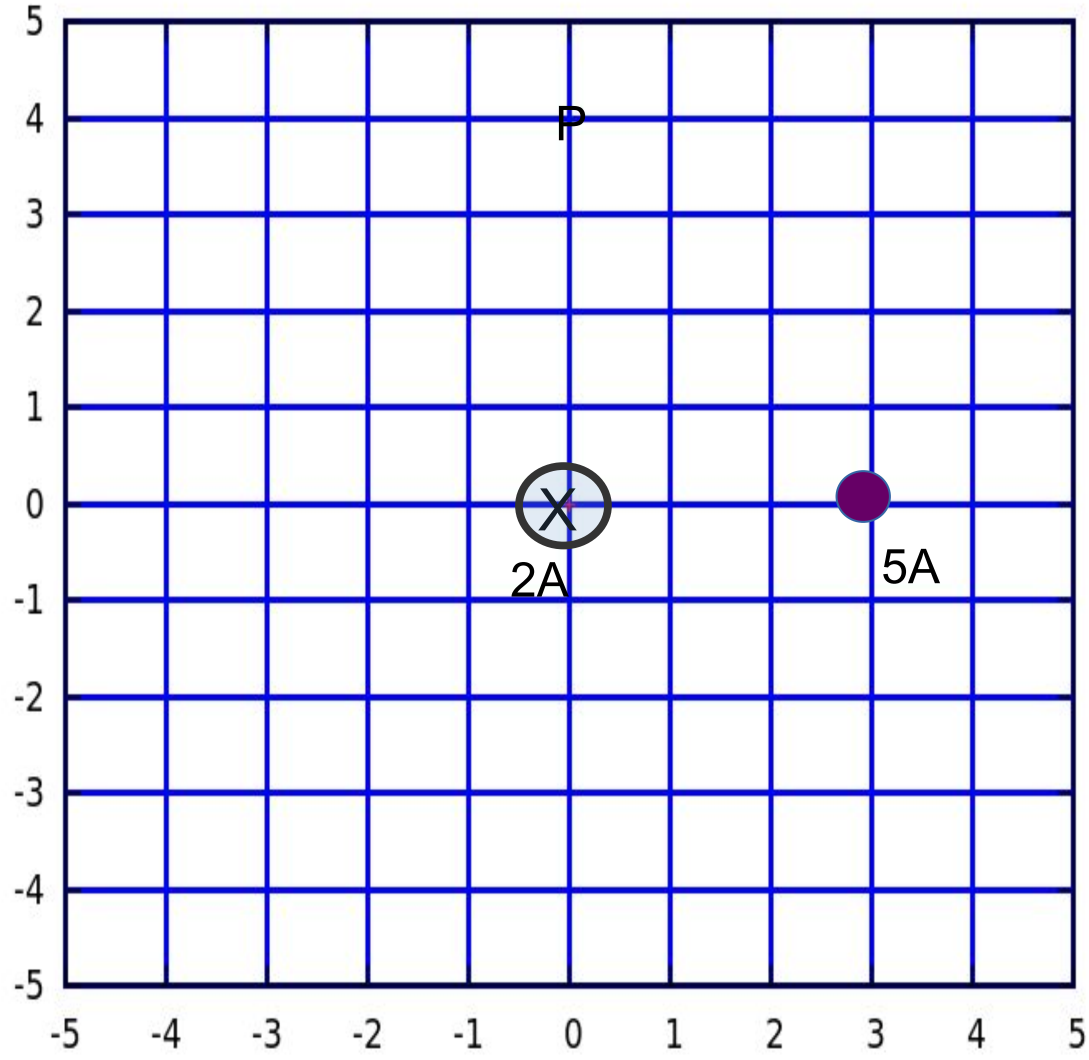
A)

B)

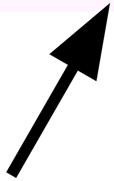
C)

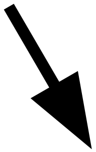
D)



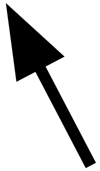


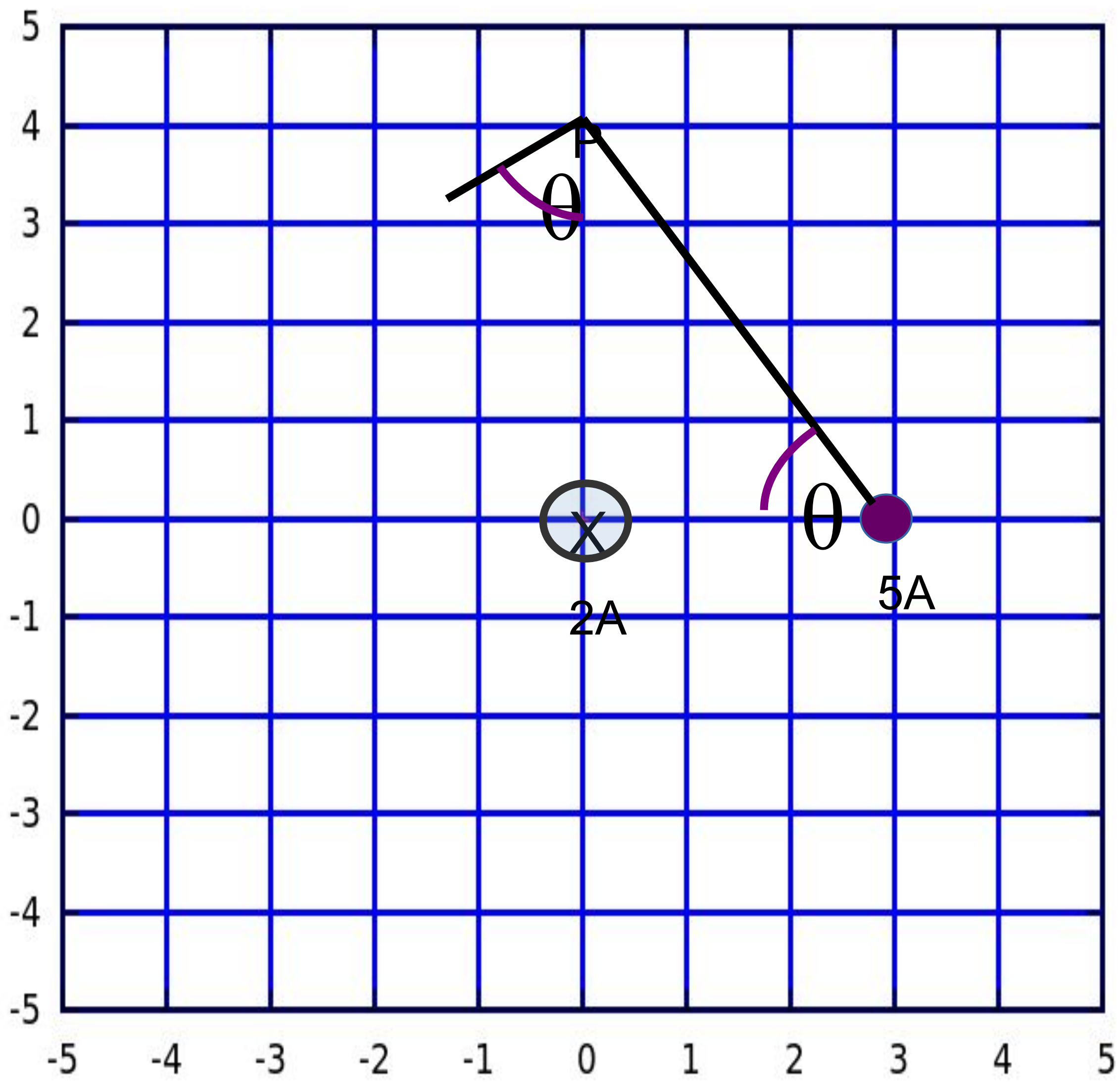
A wire carrying a current of 2A in the -z direction is now placed at (0,4)? In which direction does it deflect?

A) 

B) 

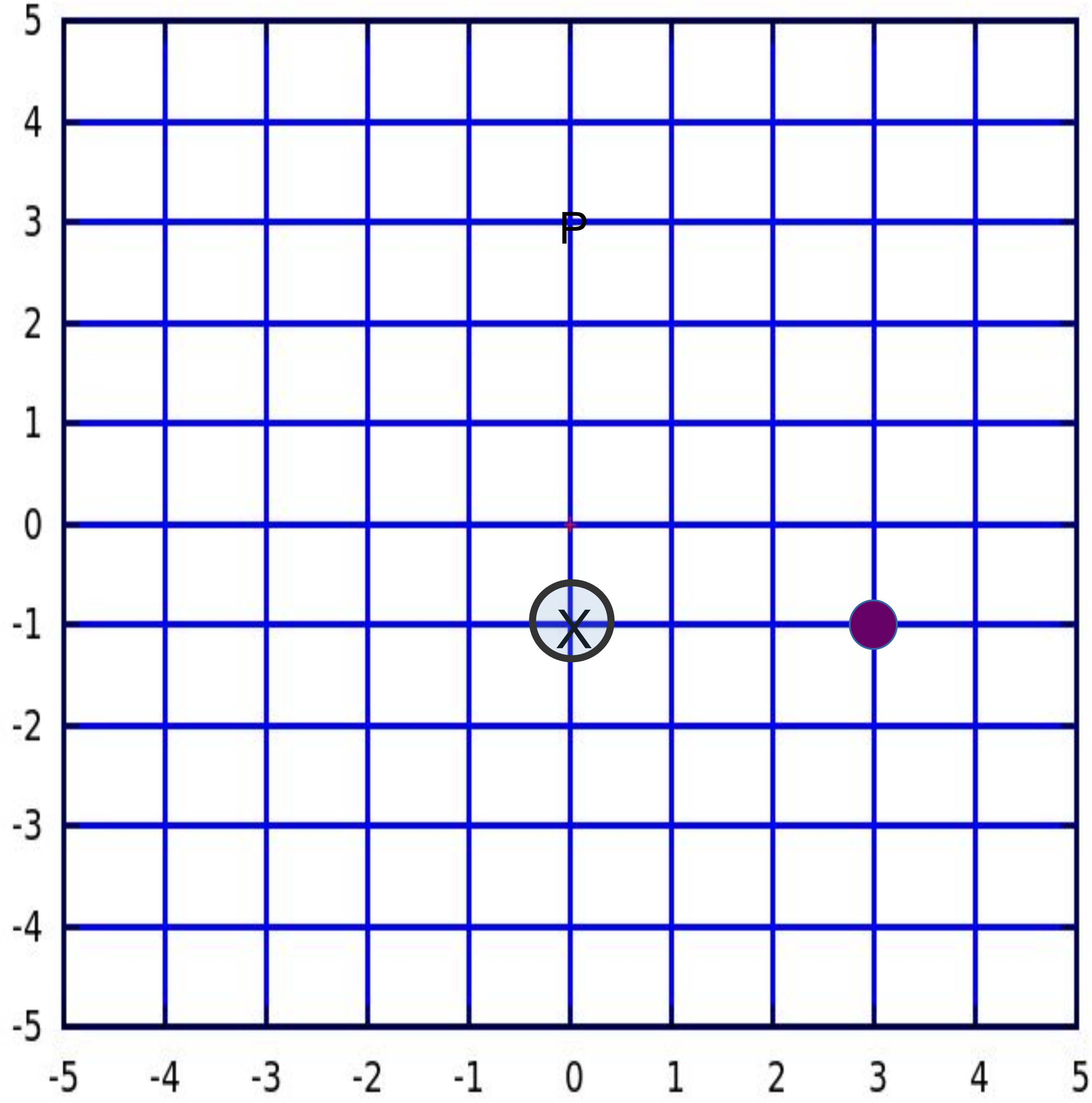
C) 

D) 



What is the value of B_x (x,y)=(0,4)?

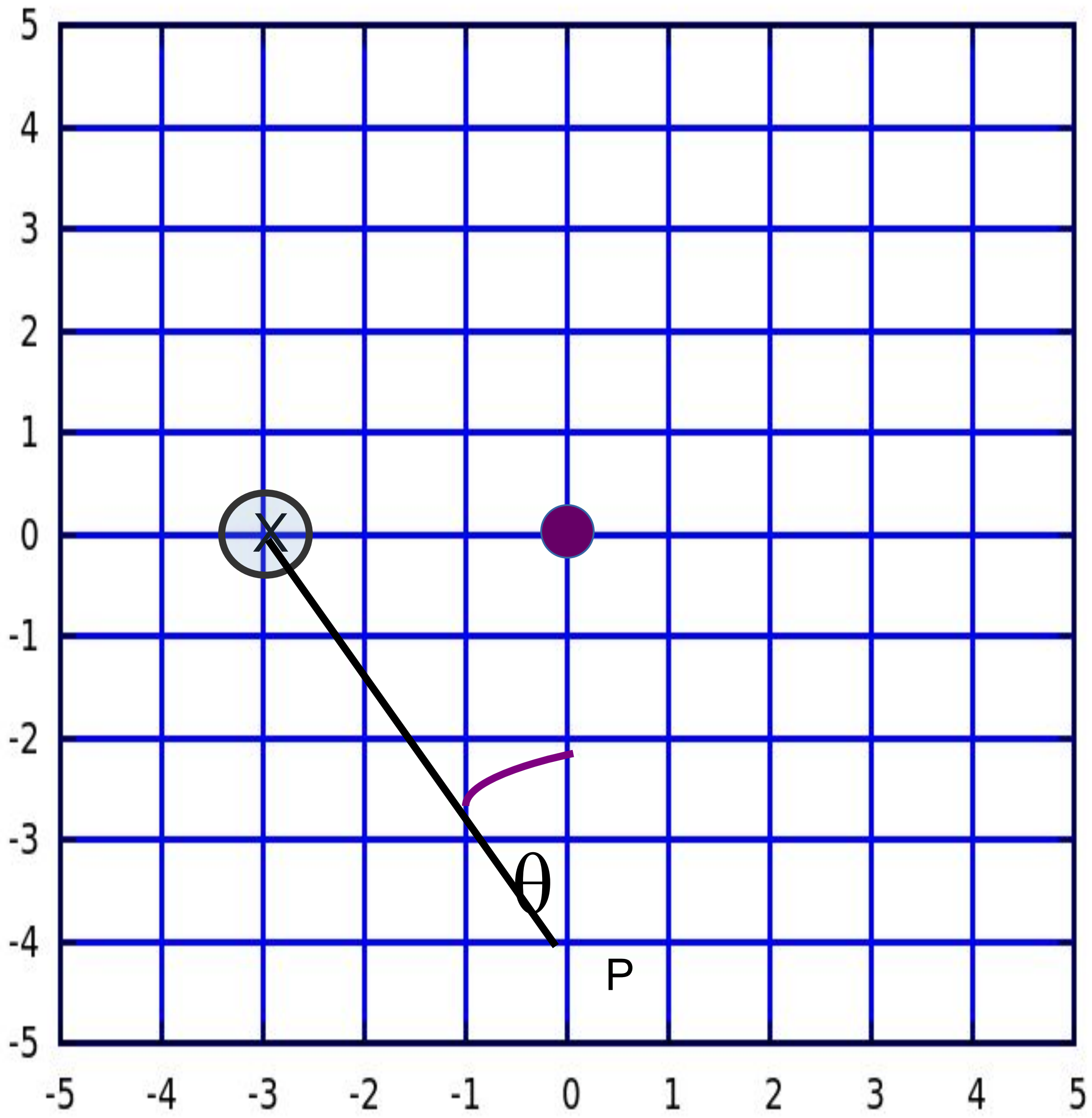
A) 0.8k' T
B) -0.1k' T
C) -0.3k' T
D) 0.6k' T
E) NOTA



What is the value of B_y (x,y)=(0,4)?

What is $B_{y,net}$ at the point P, if the left wire has 3A (-z) and the right wire has 4A (+z)

A) -0.461k'
B) 0.461k'
C) 0.637k'
D) -0.637k'
E) NOTA



What is $B_{x,net}$ at the point P, if the left wire has 3A (-z) and the right wire has 4A (+z)

A) -0.461k'
B) 0.461k'
C) 0.637k'
D) -0.637k'
E) NOTA

Faraday's Law:

Induced Voltage from changing external magnetic field B_{ext} within a loop ("EMF")=Change in magnetic 'flux' Φ (#field lines penetrating loop) with time

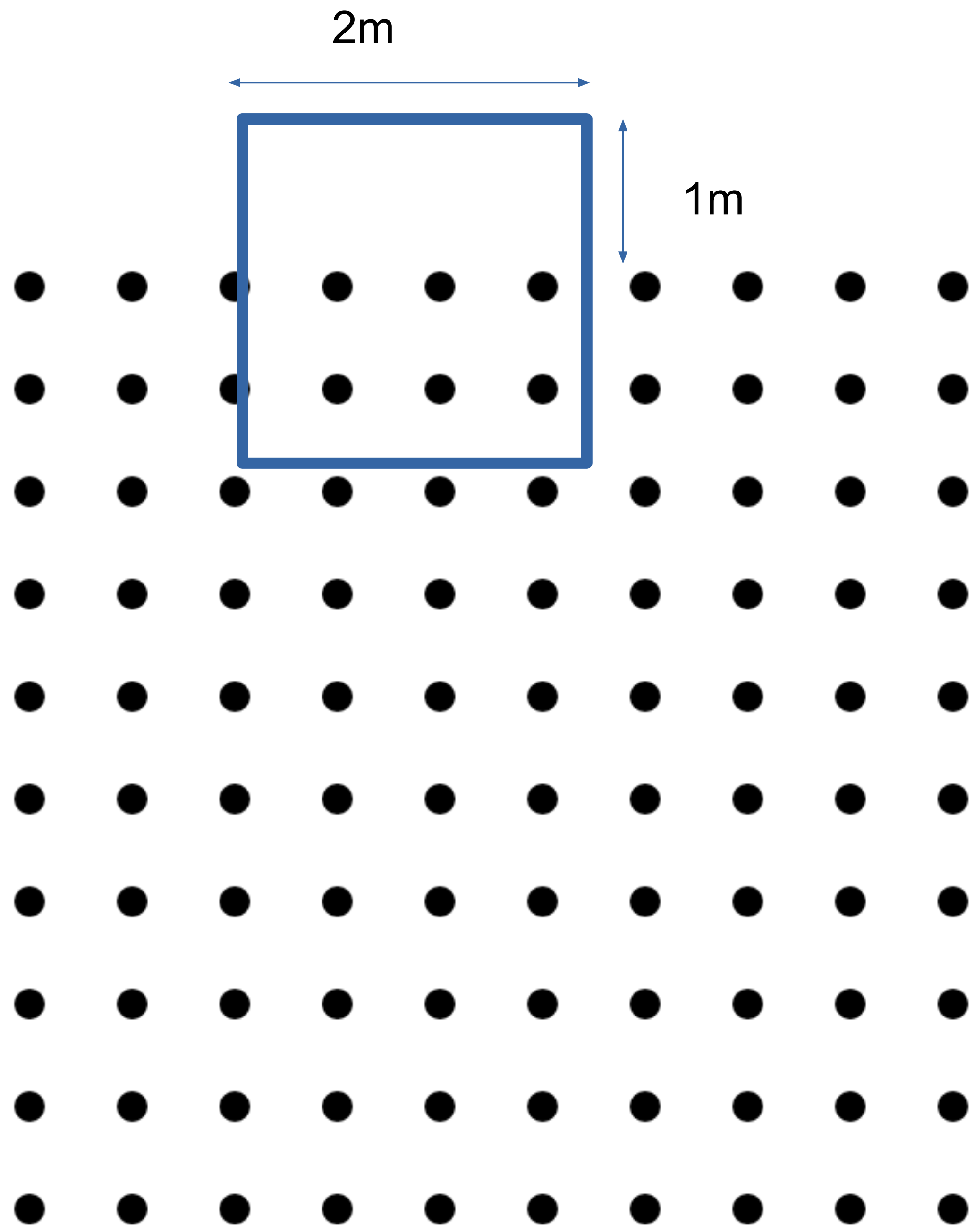
Magnetic flux $\Phi=|B_{ext}||A_{loop}|\cos\theta_{B,A}$;

$V=-\Delta\Phi/\Delta t$; (-: Lenz' Law: Induced current in loop creates $B_{induced}$ which tries to negate change in B_{ext})

If induced current=I and length of side of loop=d,

Magnetic deflection force from B_{ext} on I given by F=IdB

$V=-L\Delta I/\Delta t$ is voltage across inductor


2m
1m

If B is decreasing at a rate of 2T/s, and loop resistivity is ρ=4Ω/cm, what is the current induced in the loop?

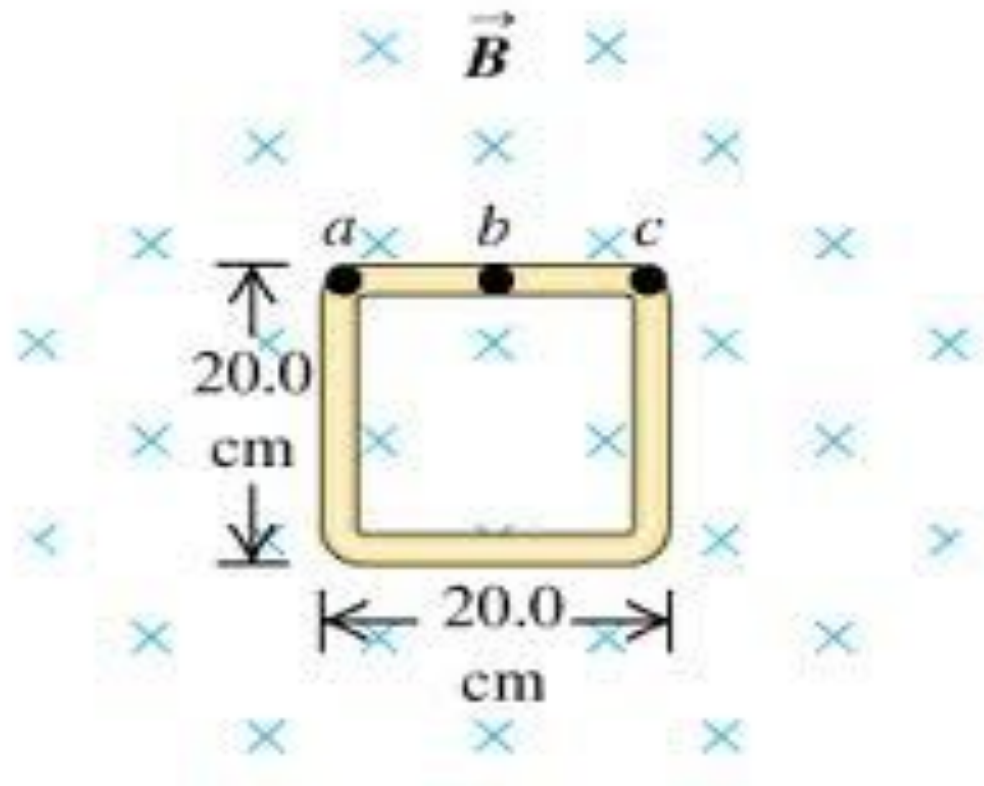
A) 2.5 A, counter-clockwise

B) 0.25 mA, clockwise

C) 1 A, c.

D) 4 mA, c.c.

E) NOTA



In the previous problem, as the field decreases, the net F=ILB makes the loop

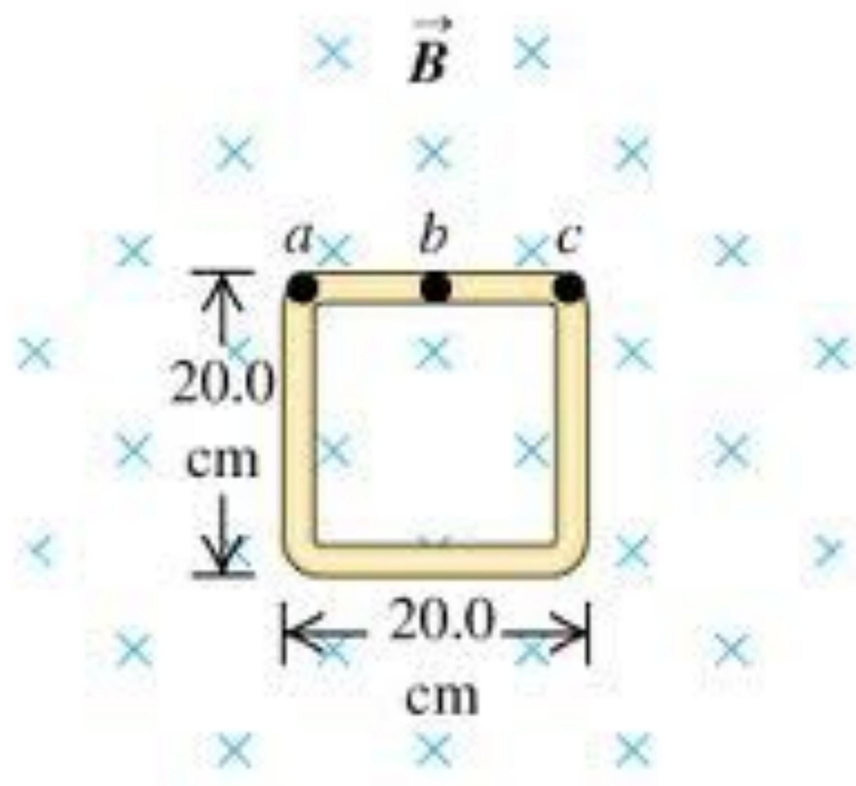
A) Spin in the plane of the page about its center

B) Remain stationary

C) Rotate about the y-axis

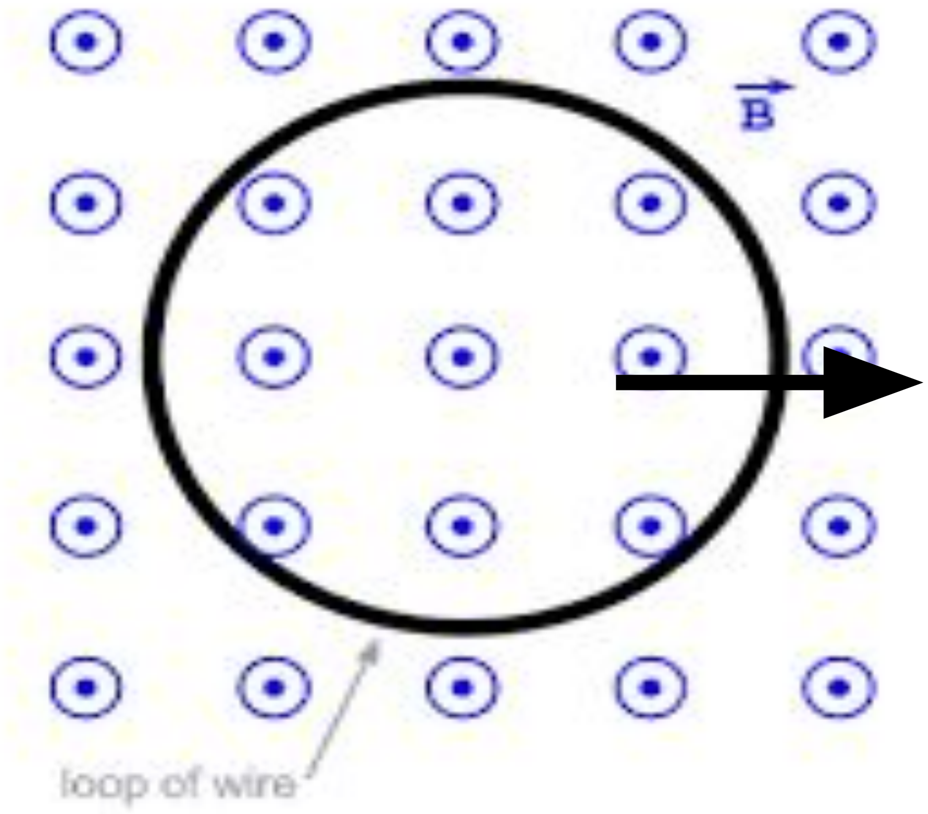
D) Rotate about the x-axis

E) NOTA



As the loop moves out of the B-field region, what current direction is induced?

A) Clockwise
B) Counter-clockwise
C) Zero



What is $V_{induced}$ in the 1 m-radius circular loop below, which moves from A→B in 4 s, given that B_A=3T (-z) and B_B=2T (+z)?

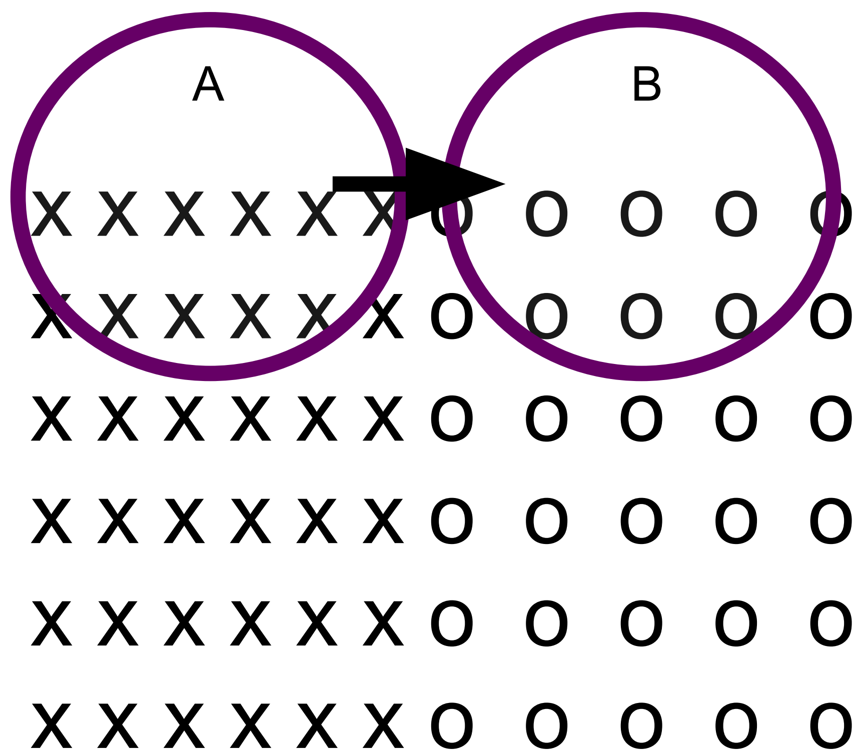
A) $5\pi/4$ V

B) $5\pi/8$ V

C) $3\pi/4$ V

D) $2\pi/4$ V

E) NOTA



What is direction of $I_{induced}$ as the loop is centered at the three points in the field region shown? Assume it is moving at constant v, and that the magnitude of B is indicated by the density of the field lines.

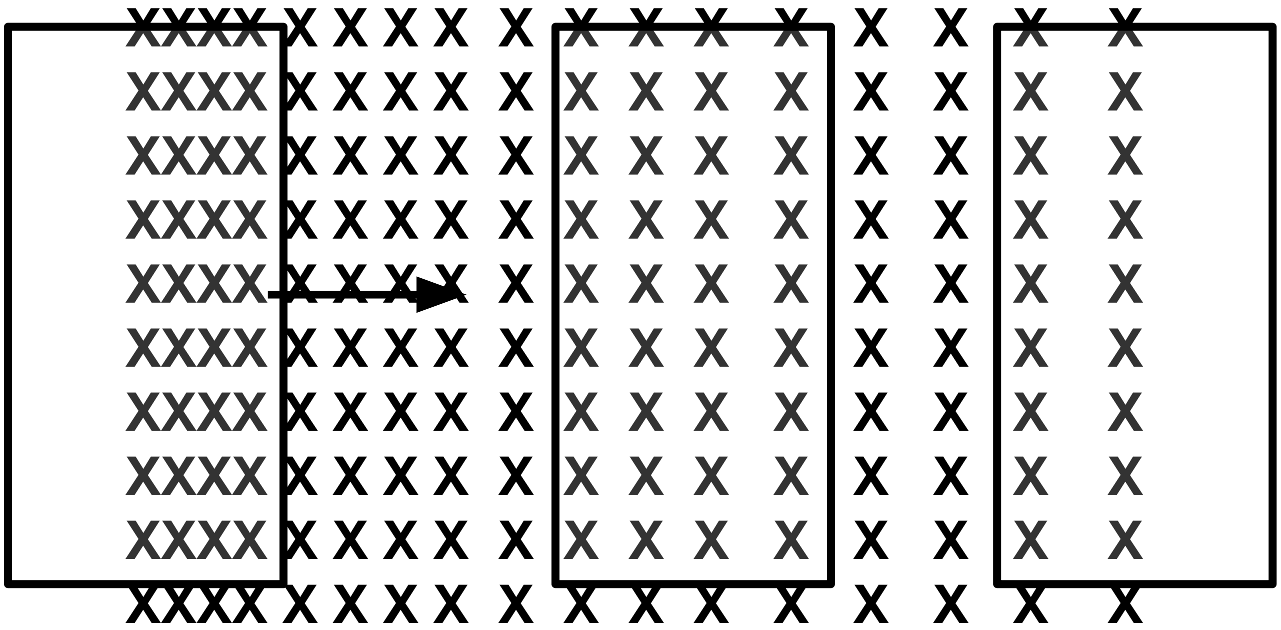
A) C, CC, C

B) CC, C, C

C) C, C, C

D) CC, CC, CC

E) NOTA



In the previous problem, when the loop is fully immersed in the field region, the net force is to the A) left, B) right, C) zero

A 1m x 1m loop is dragged across the B=2T (-z) region shown, with v=2m/s. Assuming the loop enters the region at t=0, what current directions are induced in the loop at times b/w 0→0.5 s, 1.5→2.5 s and 4→4.5 s?

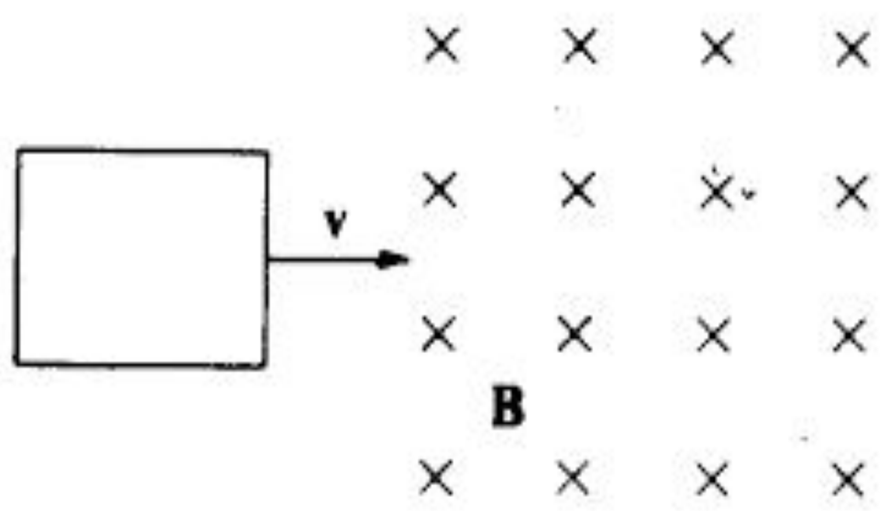
A) Clockwise, cc, clockwise

B) Cc, 0, cc

C) Cc, 0, clockwise

D) Clockwise, 0, cc

E) NOTA



If the loop has a resistance of 2Ω and is 1 m on a side, the current induced from t=0->t=0.5 s is:

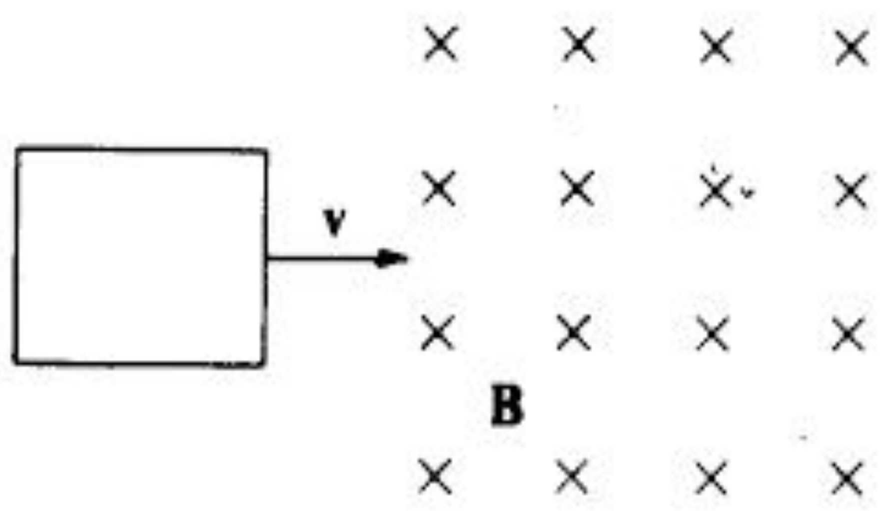
A) 0.25 A

B) 0.5 A

C) 1 A

D) 2 A

E) NOTA



Current follows a figure 8; the B fields at the centers of the left and right 'loops' point along, respectively:

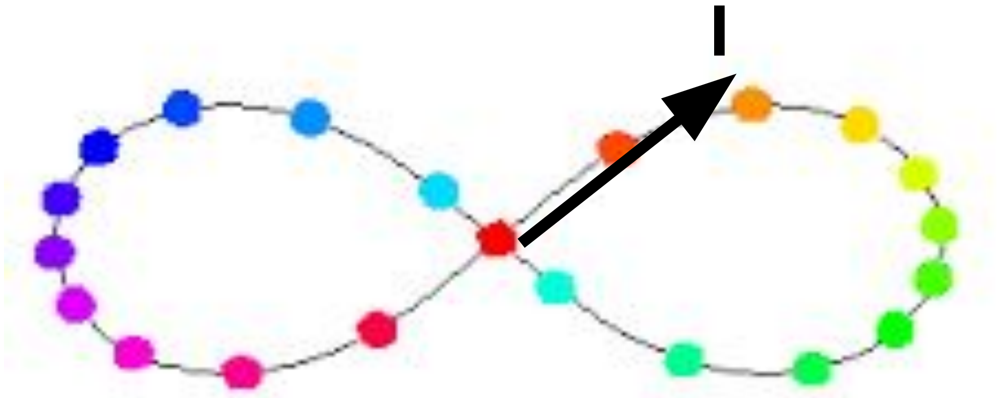
A) +z, +z

B) -z, -z

C) +z, -z

D) -z, +z

E) NOTA



A loop is centered on a B-field with B_z=+1 T on top and B_z=-1 T below. Which of the following result in current induced in the loop?

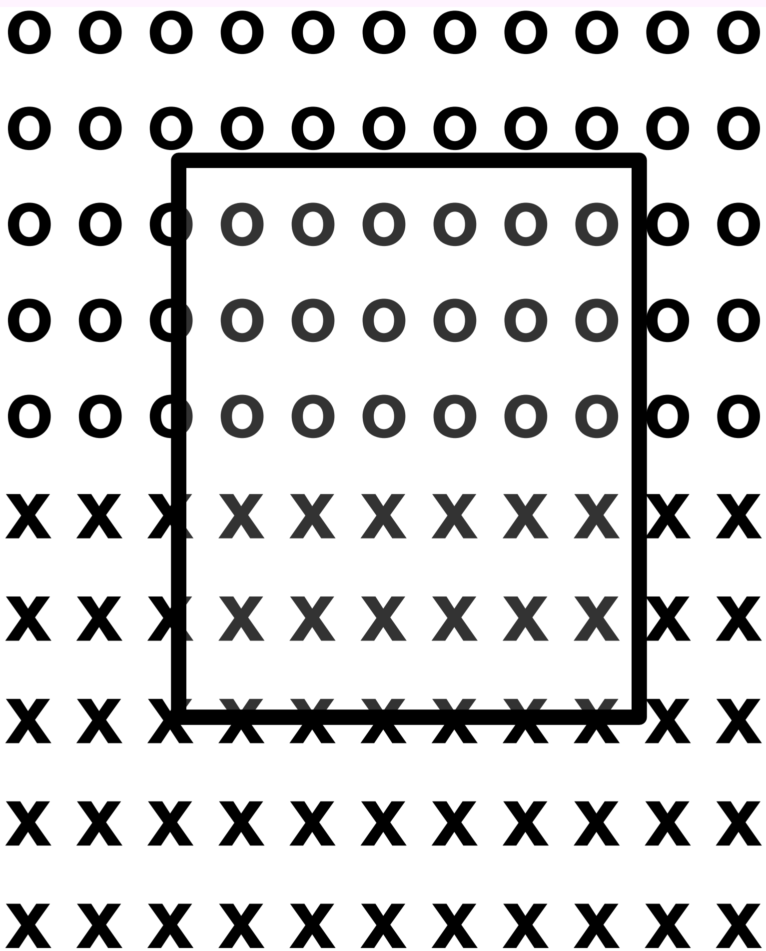
A) Rotating about y-

B) Moving along x-

C) Moving along y-

D) Increasing the magnitude of the B-field in both the upper and lower regions

E) None of the above



Imagine the loop is accelerating through the magnetic field region. At the times when the loop is entering, centered on, and exiting the external magnetic field, the direction of the induced current is:

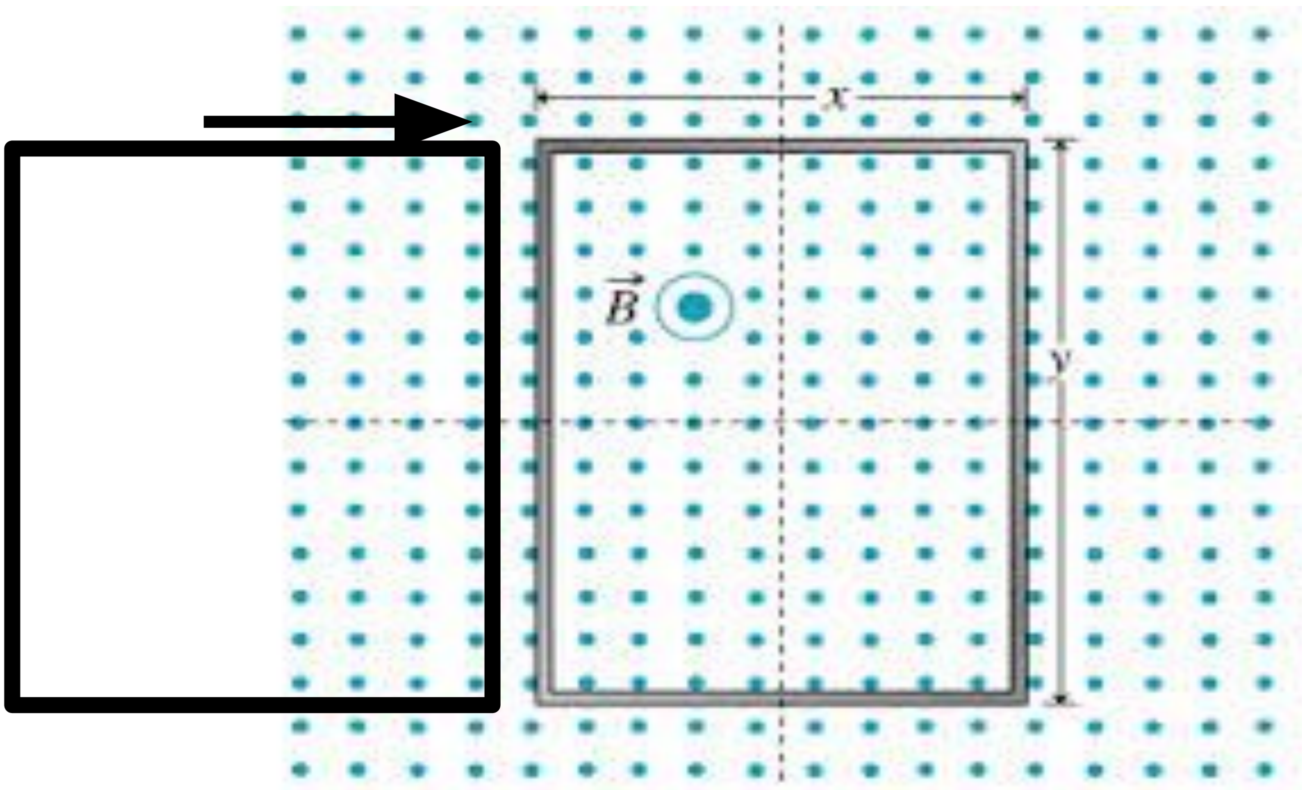
A) C, 0, CC

B) CC, 0, CC

C) C, C, CC

D) CC, 0, C

E) NOTA



A square/rectangular loop having size 3 meters x 4 meters and resistivity 4 Ohm/meter, moves in the +x direction at v=+2 meters/second, through a region with a magnetic field having magnitude 4 T and pointing in the (+z) direction and an extent of 10 meters. The amount of time that it takes for the loop to fully enter the region is:

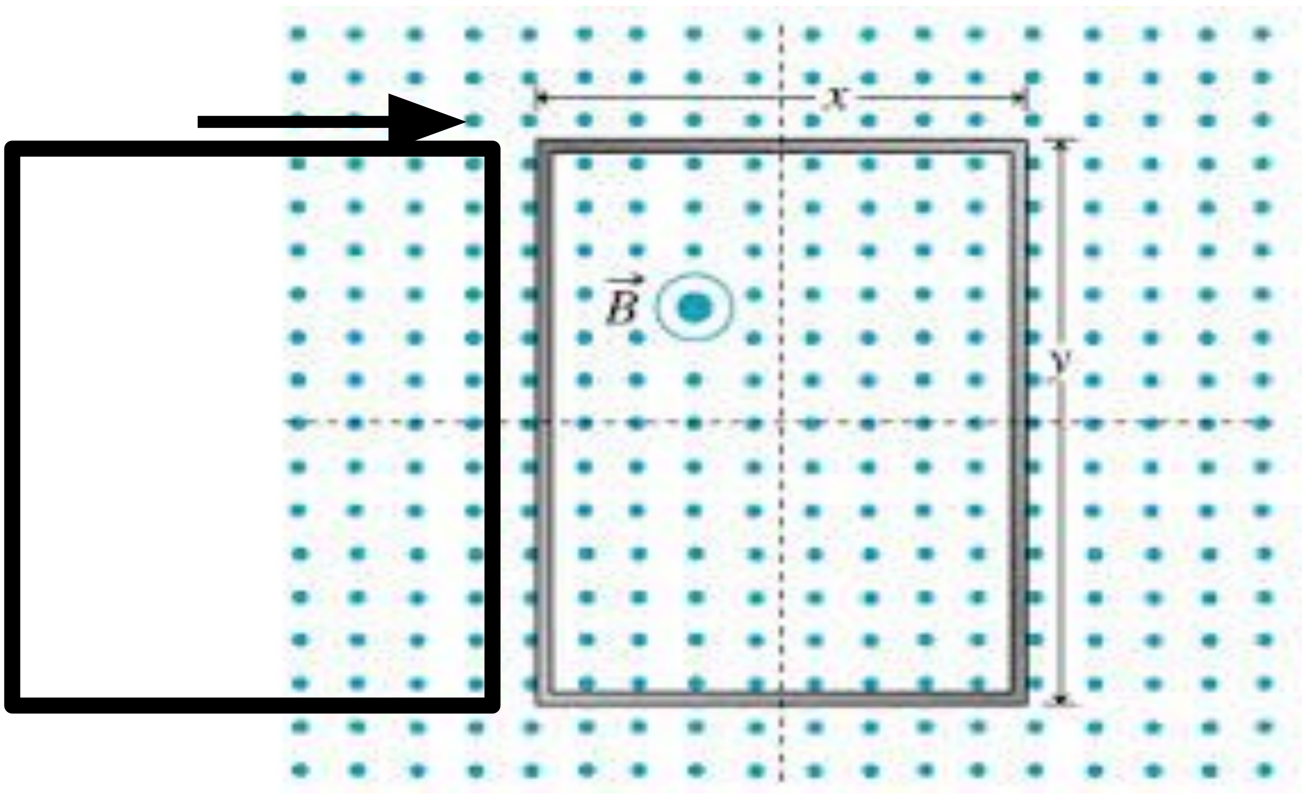
A) 1.5 seconds

B) 2 seconds

C) 3 seconds

D) 4 seconds

E) NOTA



A square/rectangular loop having size 3 meters x 4 meters and resistivity 4 Ohm/meter, moves in the +x direction at v=+2 meters/second, through a region with a magnetic field having magnitude 4 T and pointing in the (+z) direction and an extent of 10 meters. The current induced in the loop, during the time it enters the magnetic field region, is:

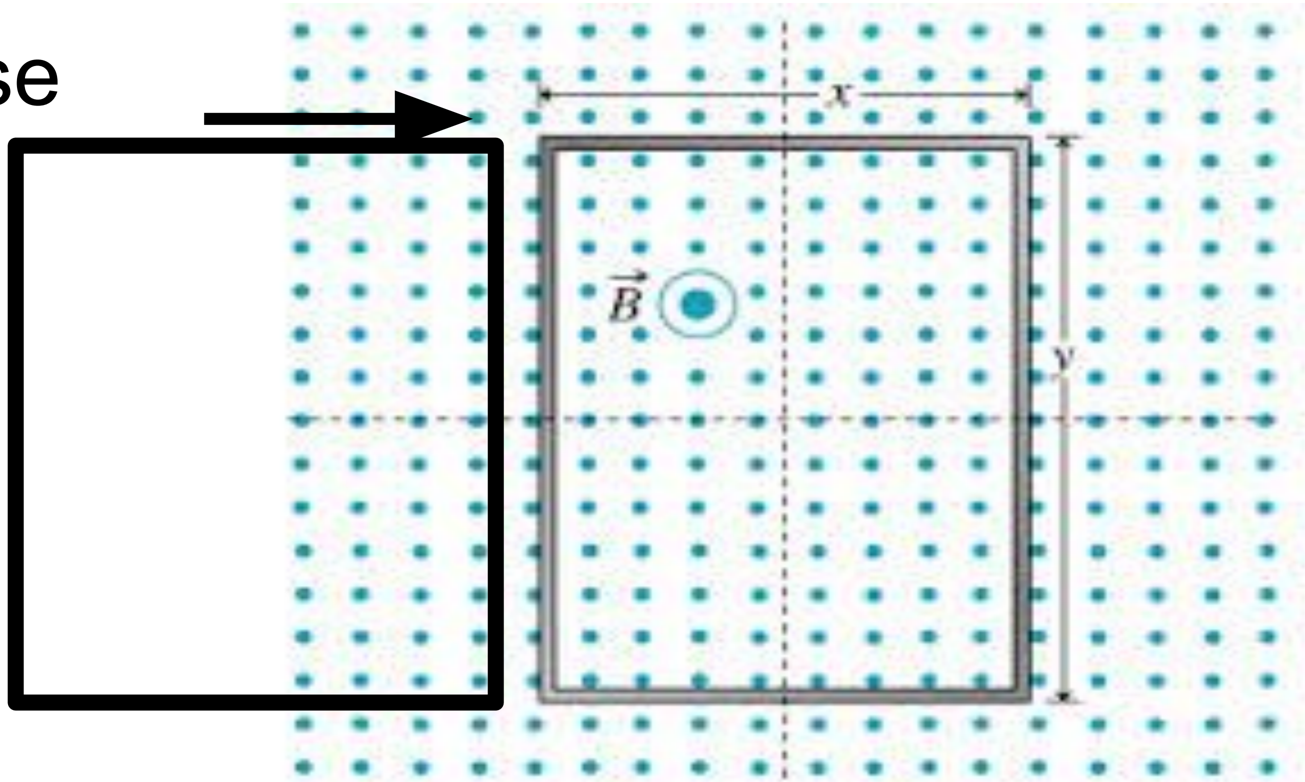
A) 1 A, clockwise

B) 1.25 A, cc

C) 0.57 A, clockwise

D) 2 A, cc

E) NOTA



A square/rectangular loop having size 3 meters x 4 meters and resistivity 4 Ohm/meter, moves in the +x direction at v=+2 meters/second, through a region with a magnetic field having magnitude 4 T and pointing in the (+z) direction and an extent of 10 meters. The magnetic force due to the external field on the right, bottom, left, and top sides of the loop as it enters, has direction:

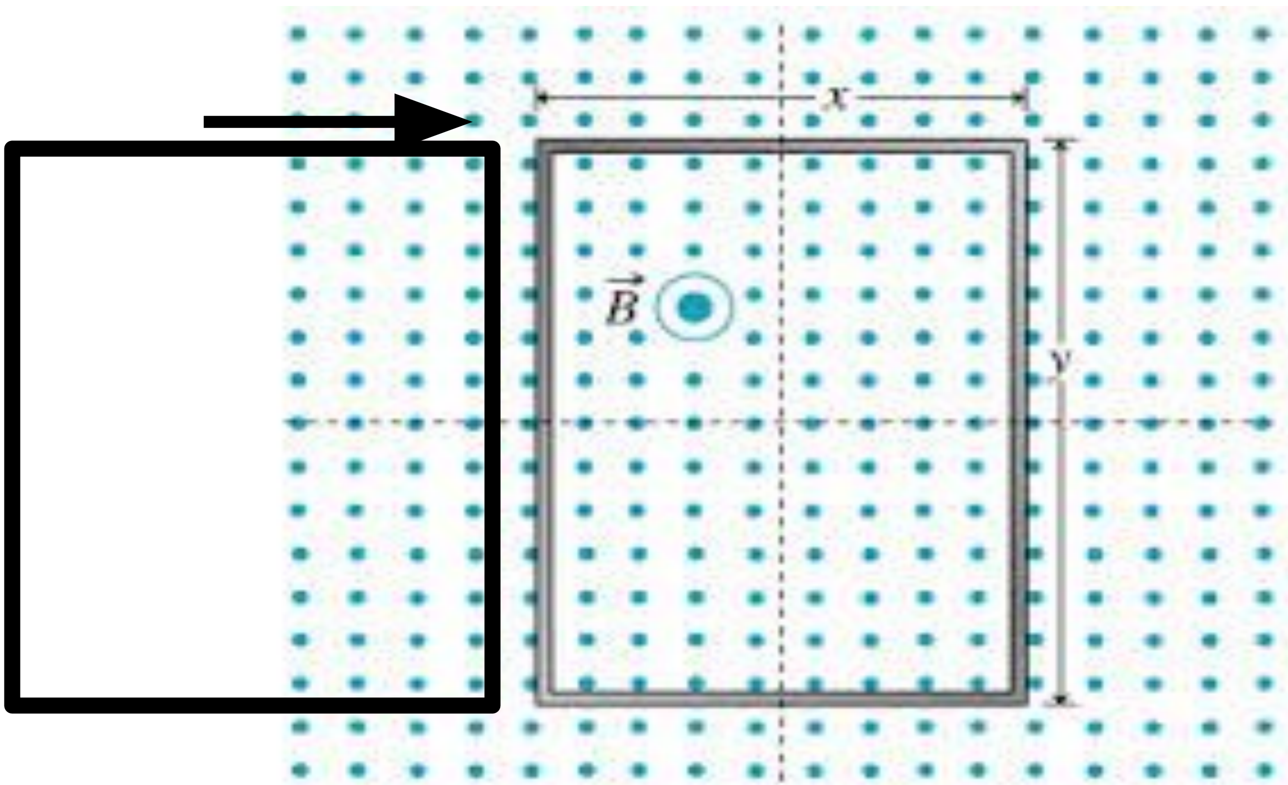
A) -x, +y, +x, -y

B) -x, +y, 0, -y

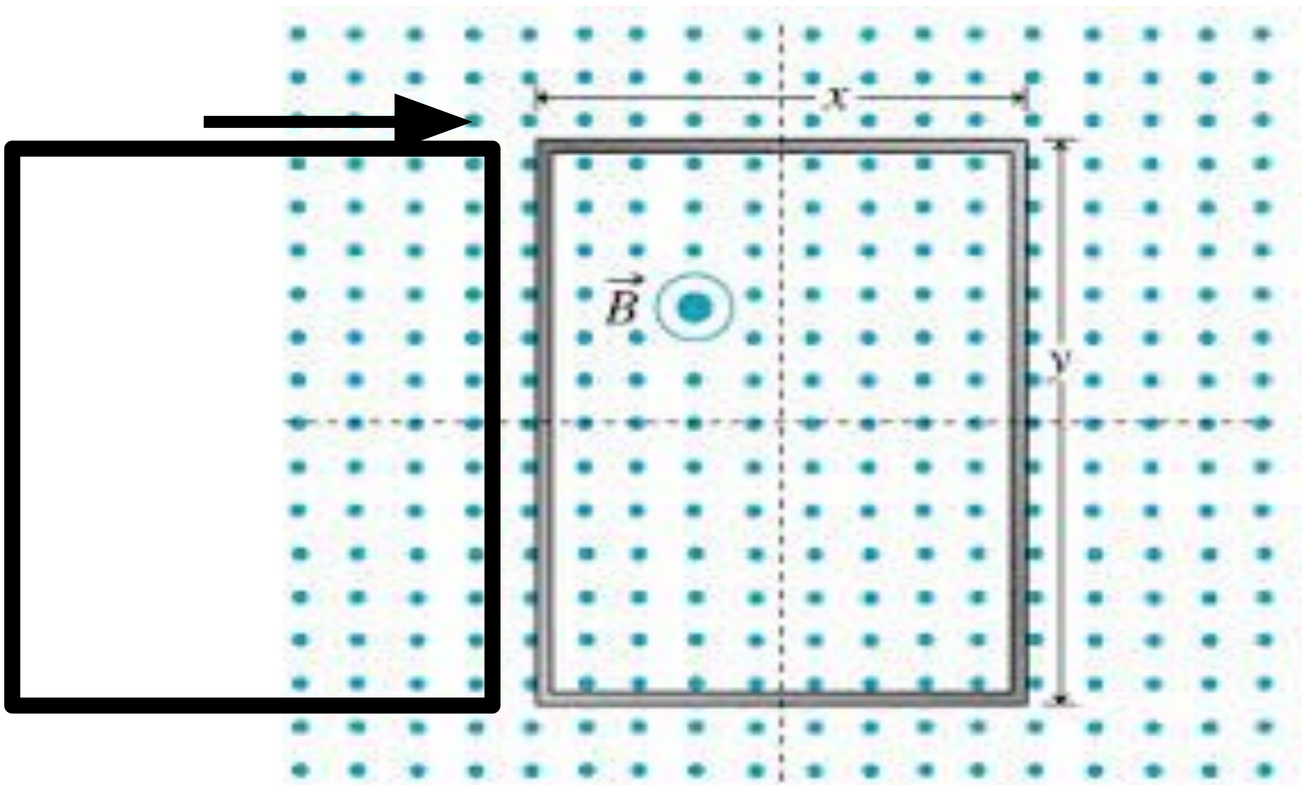
C) -x, -y, 0, +y

D) +x, -y, -x, +y

E) NOTA



A square/rectangular loop having size 3 meters x 4 meters and resistivity 4 Ohm/meter, moves in the +x direction at ***v=+1 meters/second***, through a region with a magnetic field having magnitude 4 T and pointing in the (+z) direction and an extent of 10 meters. Determine the time it takes for the loop to pass through the B-field region, and also the magnitude of the magnetic force due to the external field on the right, bottom, left, and top sides of the loop after 1.5 seconds



T to move entirely into field region: d=3 m; v=1 m/s; t=3/v=3 s

$V_{emf}=-\Delta\varphi/\Delta t$; where Flux $\varphi=BA$. So, $|V_{emf}|=(4T)(12m^2)/3s=16V$;

current=$16V/R_{tot}=16V/[(4\Omega/m)(14m)]=0.285$ Amp

Direction must be -z, so clockwise current

After 1.5s, loop half-in (as shown), force on each side from $qvB\sin\theta_{v,B}$ – v=velocity of charges forming current in wire (not v_{loop}),

For current I through wire of length l in field B: $F=IlB\sin\theta_{v,B}$

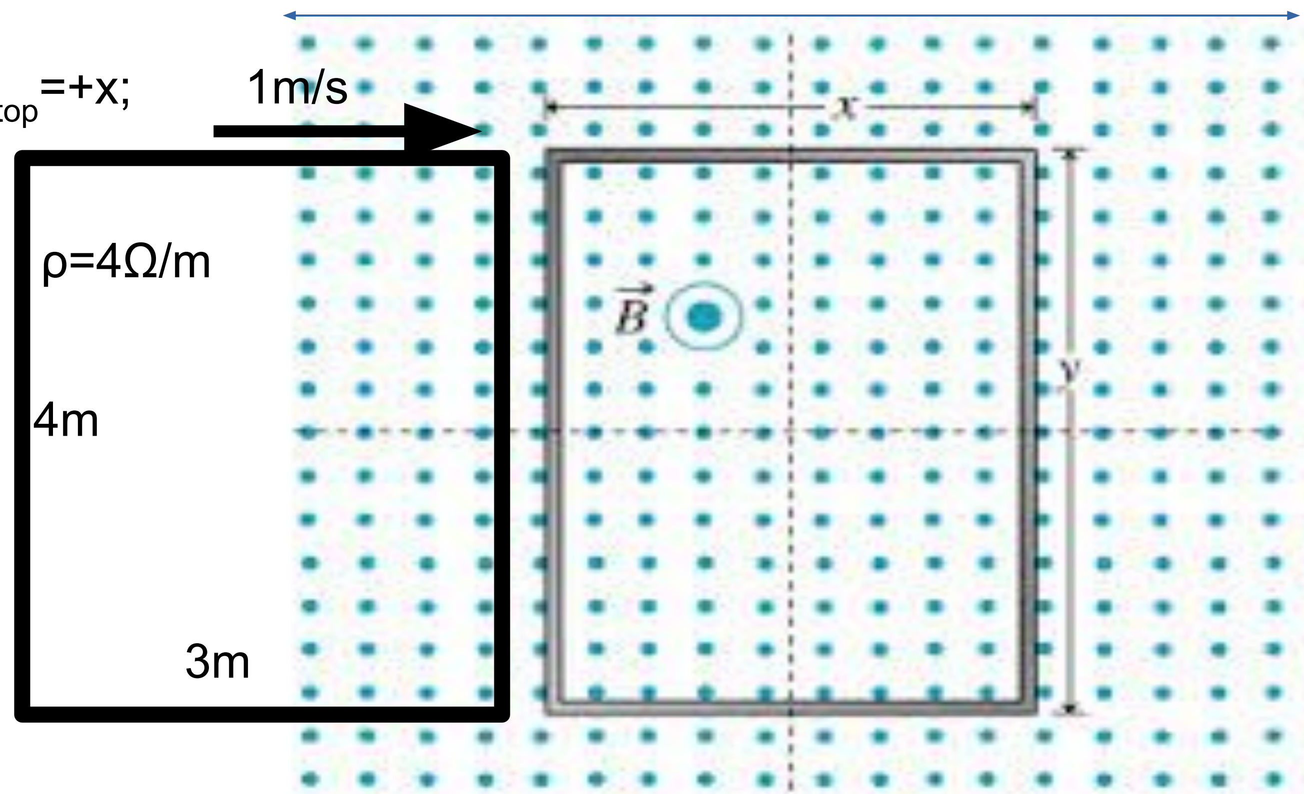
So $I_{left\ side}=+y$; $I_{bottom}=-x$; $I_{right}=-y$; $I_{top}=+x$;

$F_{left}=0$ (no B);

$F_{bottom}=(0.285A)(1.5m)(4T)$ +y

$F_{right}=(0.285A)(4m)(4T)$ -x

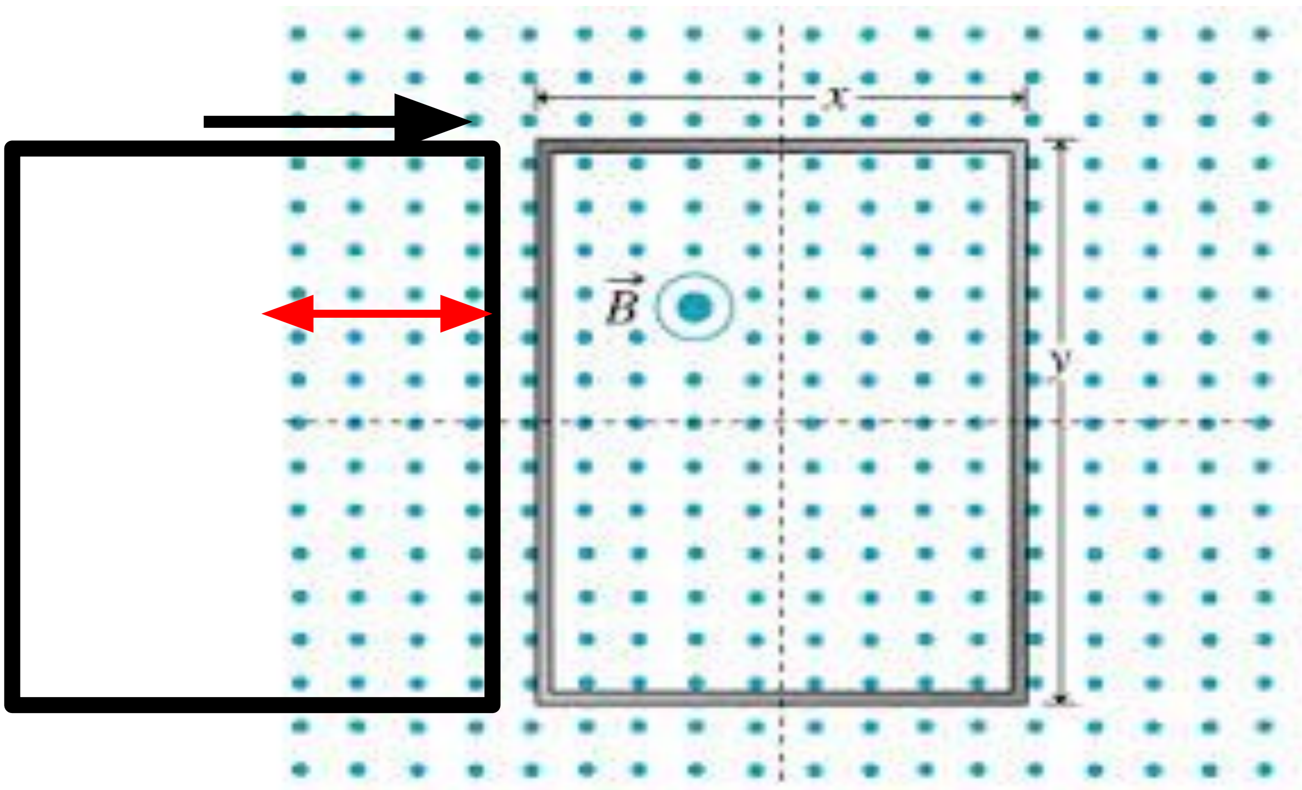
$F_{top}=(0.285A)(1.5m)(4T)$ -y



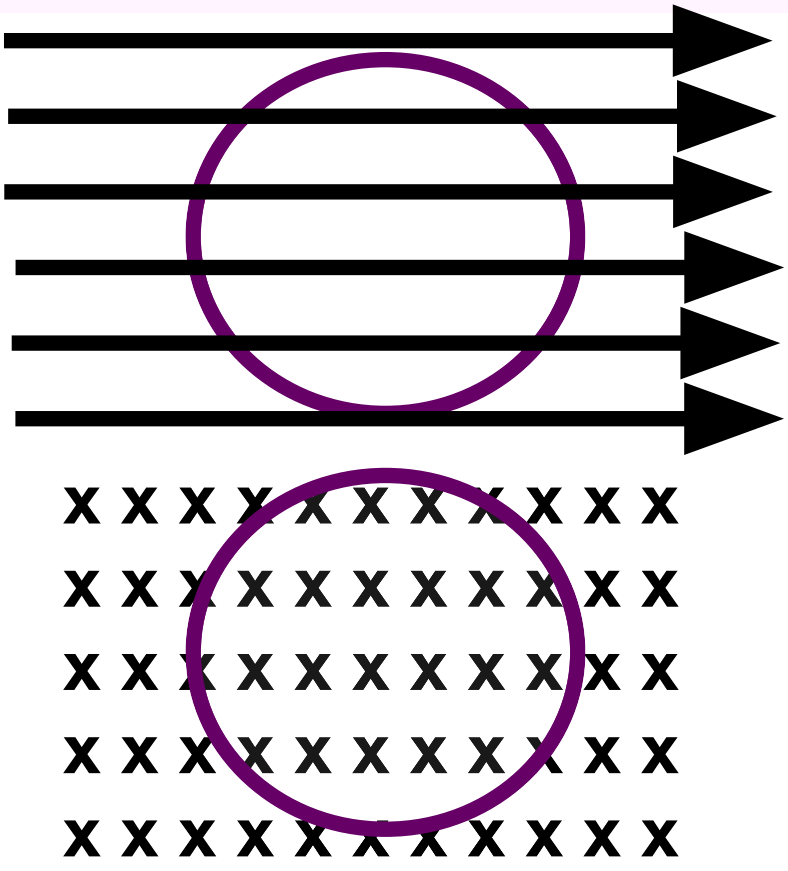
A square/rectangular loop having size 3 meters x 4 meters and resistivity 4 Ohm/meter, moves in the +x direction at v=+2 meters/second, through a region with a magnetic field having magnitude 4 T and pointing in the (+z) direction and an extent of 10 meters. At the moment shown, the magnetic force due to the external field on the right and bottom sides, has magnitude:

A) 9.12 N, 4.66N

B) NOTA



A 2 T magnetic field rotates around a 50 cm radius wire loop every 8 seconds. The voltage generated through the loop after 2 seconds is:



A) 0.25π V

B) 0.5 V

C) 0.5π V

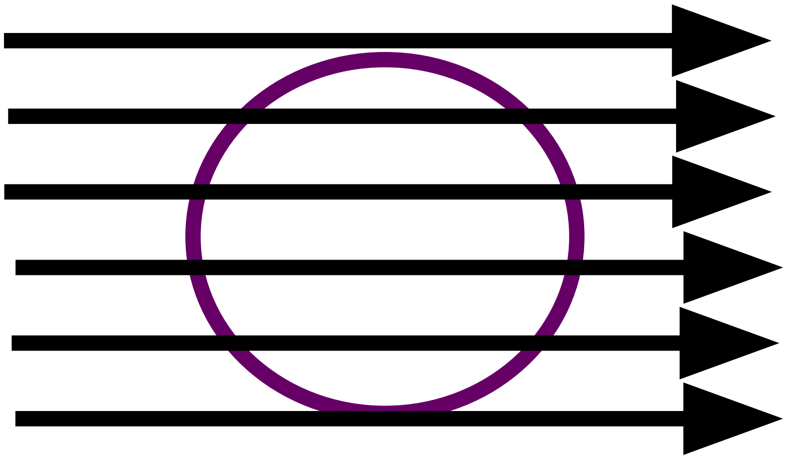
D) NOTA

The voltage generated from 0→1 s, compared to 1→2 s is:

A) smaller

B) greater

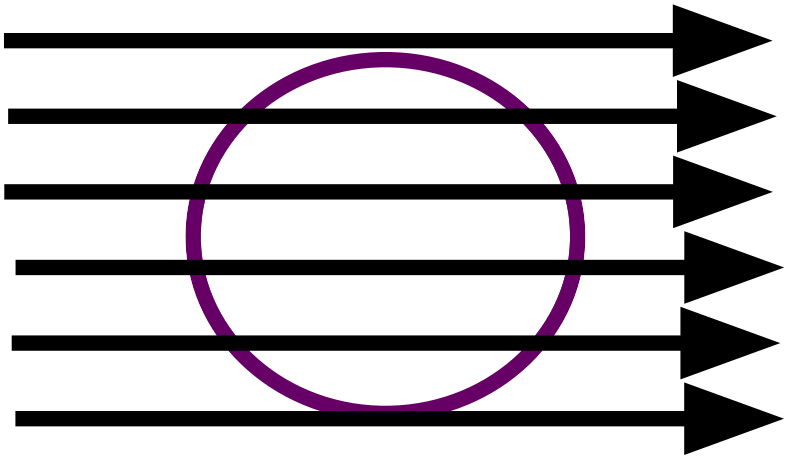
C) The same



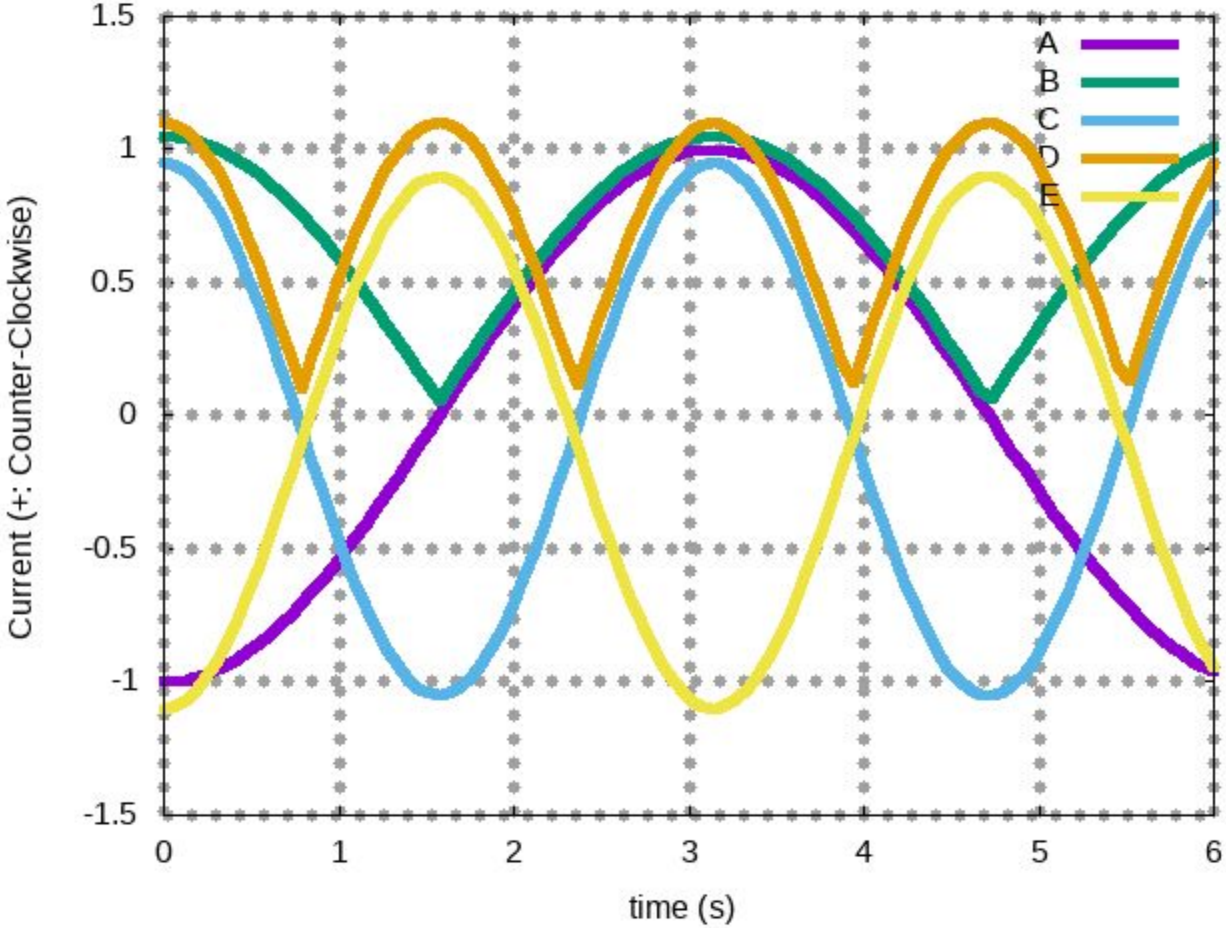
The induced current direction from 0→2 s, vs. 2→ 4 s, is

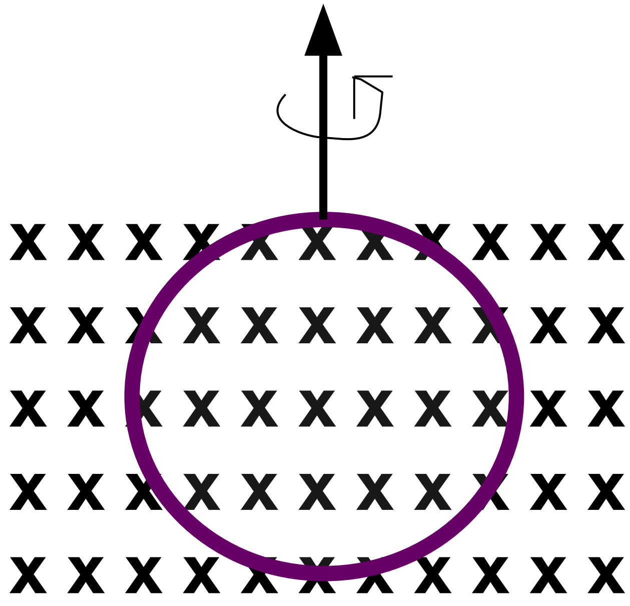
A) Opposite

B) The same

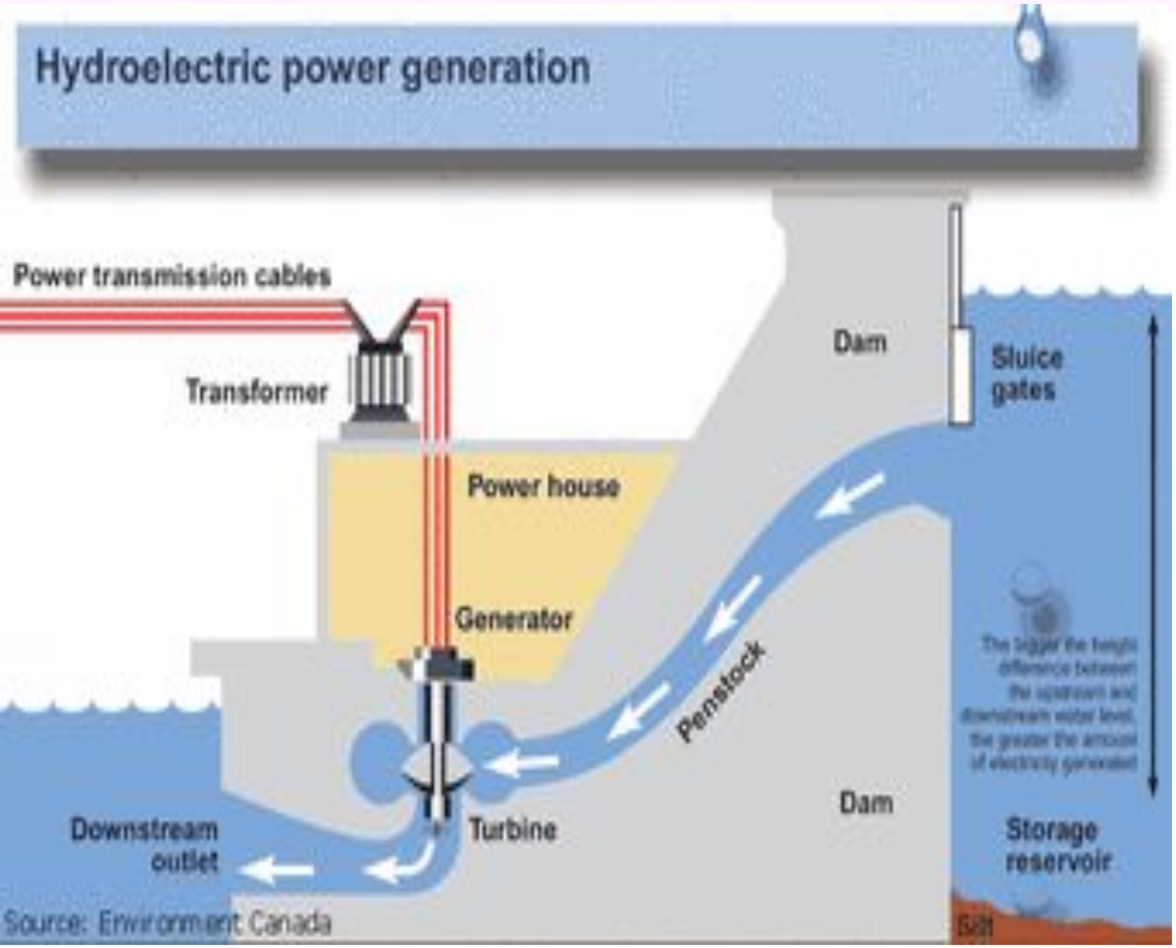


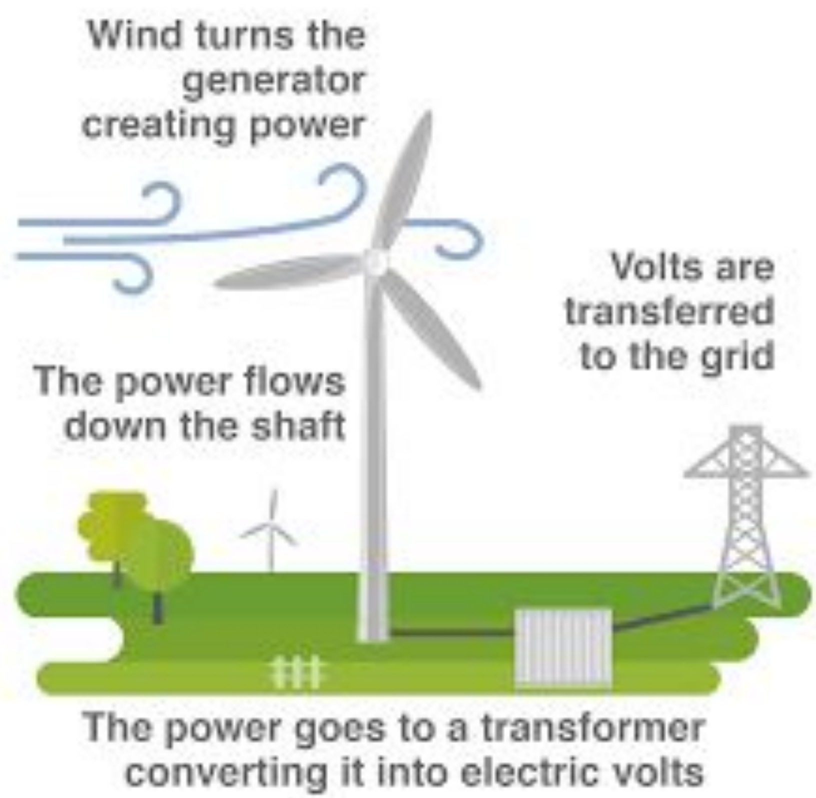
Which of the curves shown correspond to a loop being rotated as shown, once every 6 seconds?





hydroelectric/wind-power energy





Qualitatively: the KE of flowing water/air turns a loop of wire in an external magnetic field, generating a voltage/current (`electromagnet')

ρ (density)=500 kg/m^3; h=5.1 m Volume fluid=4 m^3; =>KE=10^5 J/s ;

loop: R=4 m; M=2.5 kg => I=20 ρ (resistivity)=2Ω/m, so total resistance=

At the Bowersock dam on the Kaw River, 10 m^3 of water per second falls from a height of 2m, spinning a 20 kg square wire loop 4m x 4m (resistivity ρ=1 Ω/m) immersed in an external 2T field. If the rotational inertia of the loop=½ MR^2, converting KE to PE (recall that the density of water is 10^3 kg/m^3

The rotational velocity ω of the loop is about:
A) 20 rads/s B) 16 rad/s C) 10 rad/s D) 99 rad/s E) NOTA

At the Bowersock dam on the Kaw River, 10 m^3 of water per second falls from a height of 2m, spinning a 20 kg square wire loop 4m x 4m (resistivity ρ=1 Ω/m) immersed in an external 2T field. If the rotational inertia of the loop=½ MR^2, how much time does it take for the loop to make one full turn?

A) 99 seconds B) 15.75 seconds C) 622 seconds D) 0.0634 s seconds E) NOTA

At the Bowersock dam on the Kaw River, 10 m^3 of water per second falls from a height of 2m, spinning a 20 kg square wire loop 4m x 4m (resistivity ρ=1 Ω/m) immersed in an external 2T field. If the rotational inertia of the loop=½ MR^2, given that there are 4 turns per rotation, what is the induced current over one full turn?

A) 31.5 A B) 63 A C) 126 A D) NOTA

At the Bowersock dam on the Kaw River, 10 m^3 of water per second falls from a height of 2m, spinning a 20 kg square wire loop 4m x 4m (resistivity ρ=1 Ω/m) immersed in an external 2T field. If the rotational inertia of the loop=½ MR^2, the voltage & current generated in the loop is:

A) 100V, 4A B) 12V, 100A C) 1kV, 63 A D) 10000V, 100A E) NOTA

The rotational velocity ω of the loop is about:

A) 20 rads/s B) 16 rad/s C) 10 rad/s D) 99 rad/s E) NOTA

Starting from zero, in one full turn of the loop, how many times does the induced current change direction? A) 1 B) 2 C) 3 D) 4 E) NOTA

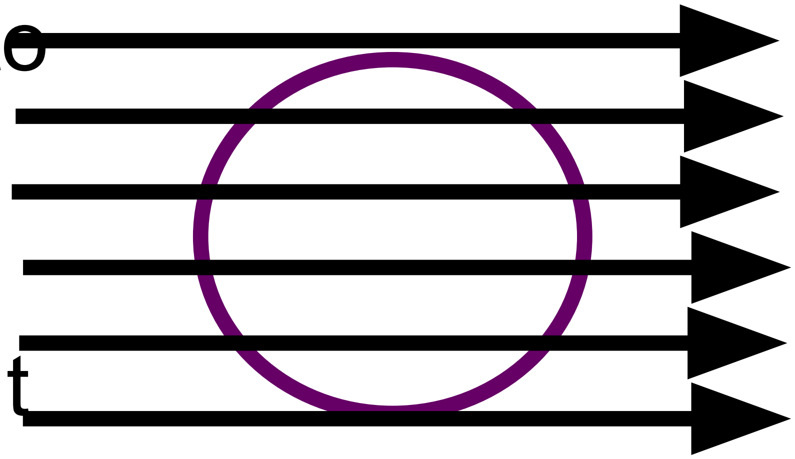
Calculating the change in area ΔA in each turn and using $\omega=2\pi/T$, the induced voltage/current in the loop is: A) 1008V, 63A B) 4V, 4A C) 4V, 64A D) 64V, 4A E) NOTA

If the loop is at 45 degrees wrt to the field with a clockwise current as viewed from behind the loop, which is true of the force on the loop?

A) Torque tends to rotate the loop into the field

B) Torque tends to rotate the loop out of the field

C) There is no torque



Find the magnetic field generated by an electron ($q=1.6 \times 10^{-19}$ C) orbiting in a circle of radius 5.29×10^{-11} m with velocity 2.19×10^{6} m/s around a proton in Hydrogen

A) 10^{-12} T

B) 10^{-9} T

C) 10^{-6} T

D) 10^{-3} T

E) 1 T

An average current of 0.1 A flows, over a period of 0.02 seconds, across an 800 turn, 10 cm diameter solenoid of the Davemobile*. What is the induced voltage?

A) 0.0004 V

B) 0.004 V

C) 0.04 V

D) 0.4 V

E) 4 V

See my e-how-to-pop-a-solenoid online video

Inductors (symbol=`L'; units=Henries)!

The magnetic equivalent of capacitors – capacitors work by storing electrical energy ($PE=Q^2/2C$) in the charge that accumulates on the capacitor plates. Inductors, which are just loops of wire, work by storing magnetic energy. The voltage magnitude through an inductor at some time is given by: $V_L=L\Delta I/\Delta t$ Note that the effect of an inductor in a circuit is greatest when the circuit is initially connected, since at that time the flux through the loop increases from zero to some non-zero value. Time dependence of an inductor is thus opposite to a capacitor – at t=0, inductor blocks current into branch containing it, and has all the voltage drop in that branch. As t→infy, inductor is equivalent to a 'straight wire'. $\tau(RC)=RC$; $\tau(LR)=L/R$

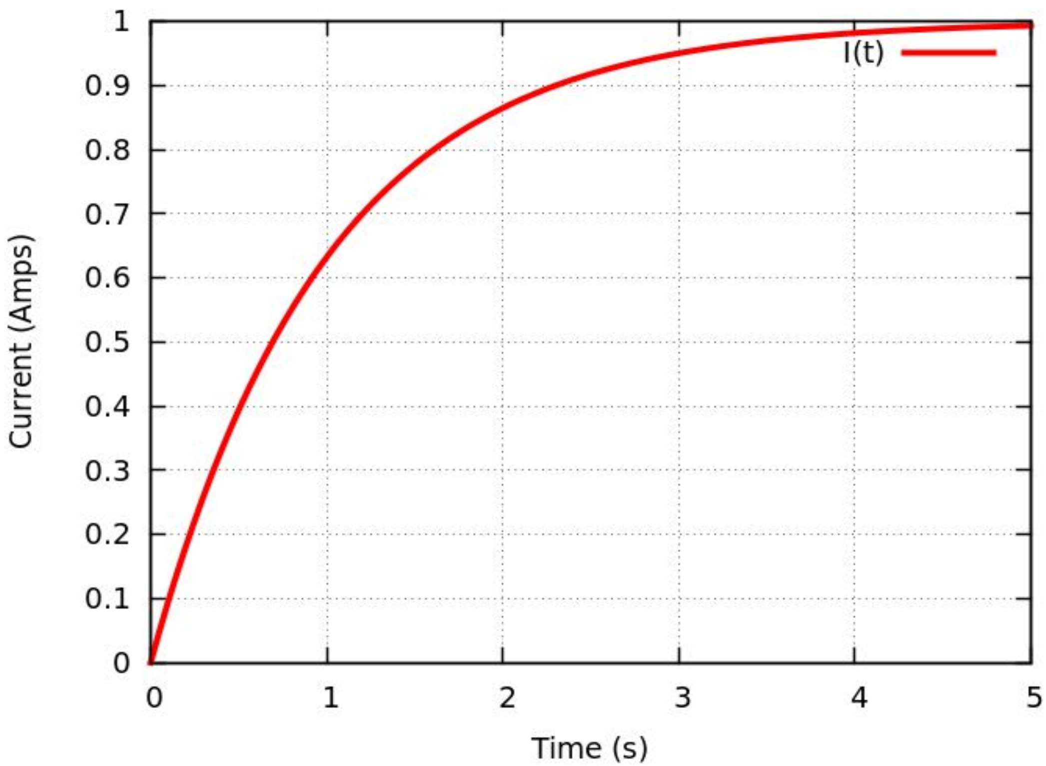
Which of the following would have the effect of steepining the I(t) curve shown below?

A) increasing the size of the circuit

B) increasing the resistance in the circuit

C) both of the above

D) NOTA



Which of the following would best describe the inductance of a square loop of wire length l on a side, with resistance R?

A) L~l/R

B) L~1/(Rl)

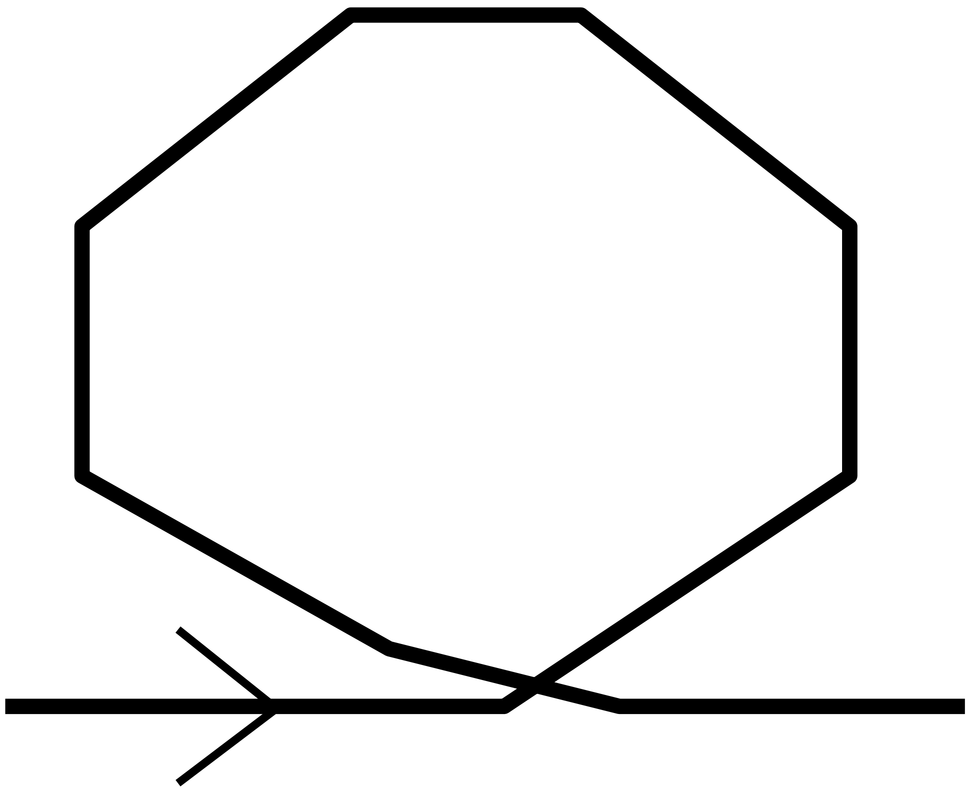
C) L~Rl

D) L~R/l

A current begins to flow through the loop shown. The loop responds with a voltage in which direction?

A) Clockwise

B) CC



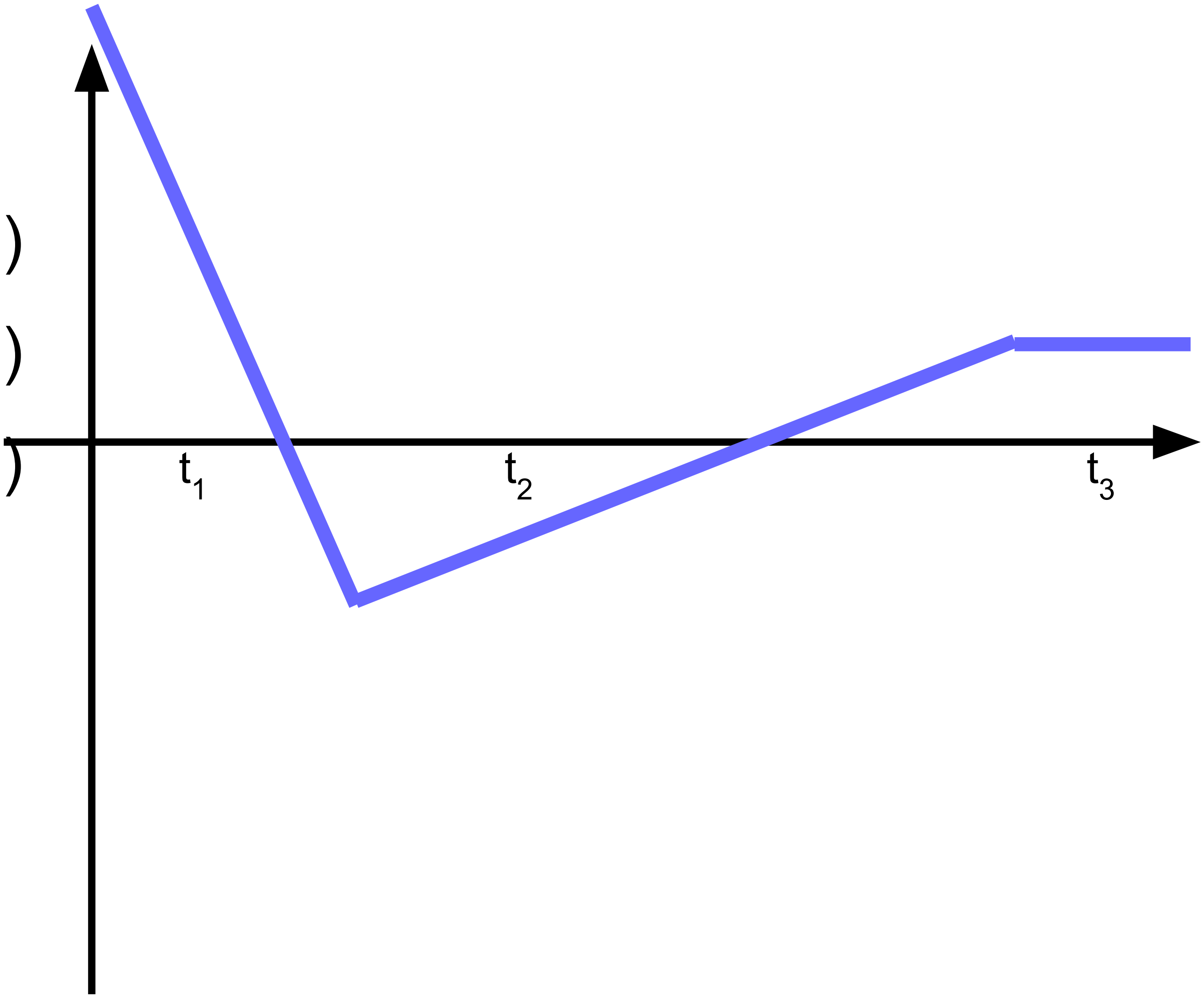
Given the graph shown of B(t) through a loop, the ranking of the induced voltage magnitude is:

A) V(t1)>V(t2)>V(t3)

B) V(t1)<V(t2)=V(t3)

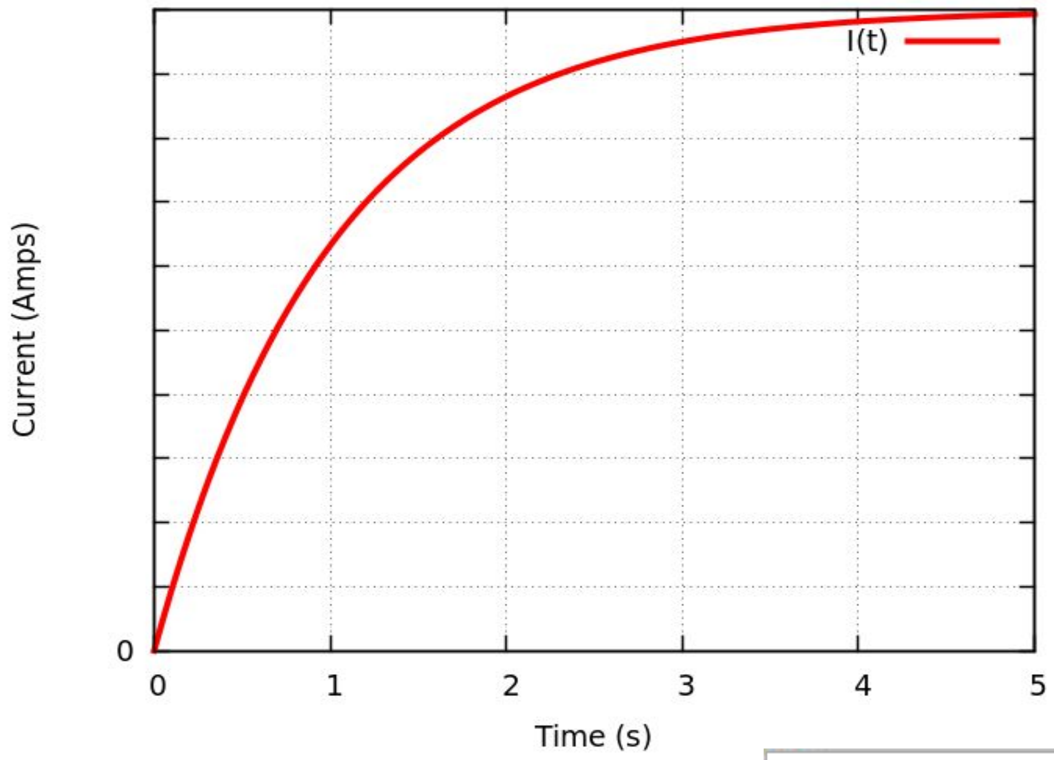
C) V(t1)<V(t2)<V(t3)

D) NOTA



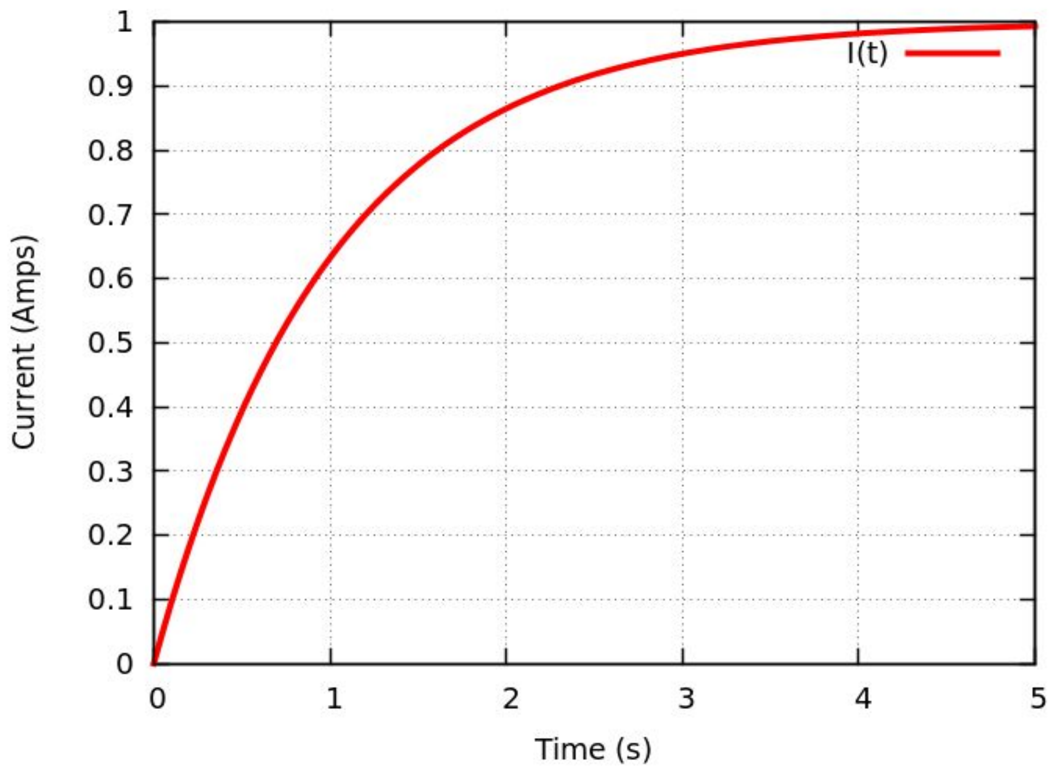
Given I(t) for an RL circuit with V=4V, what is the approximate value of V_L(2 s)?

A) 0.8 V
B) 0.3 V
C) 4 V
D) 1.8 V
E) 10 V



In the problem below, what is the approximate value of L?

A) 0.008 H
B) 0.08 H
C) 0.8 H
D) 8 H
E) 80 H



In which of the circuits below does current rise fastest*?

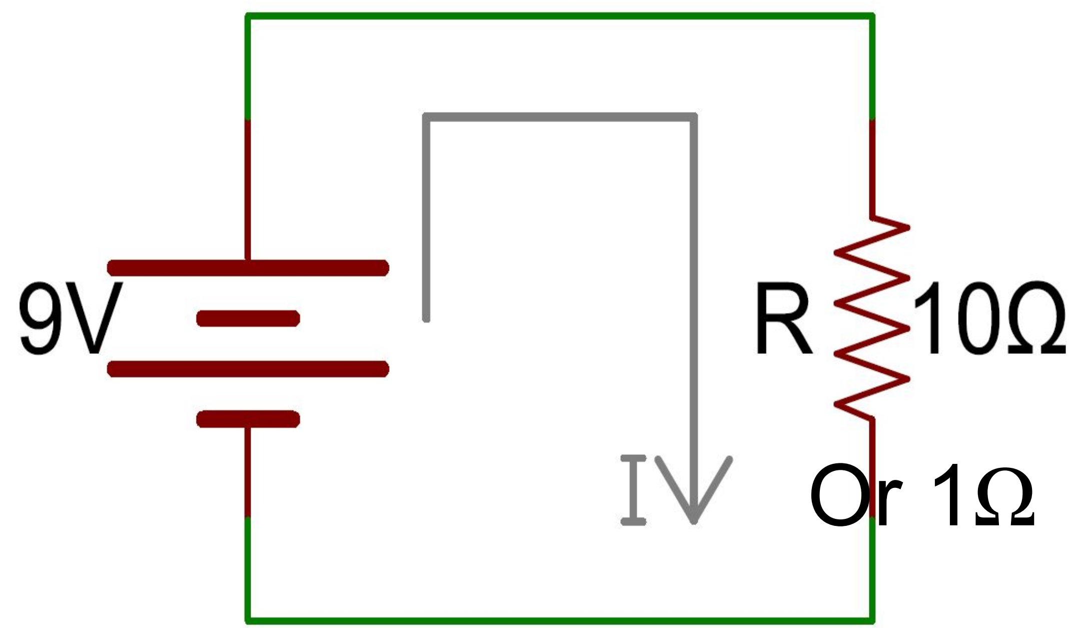
A) V=9V connected to R=1Ω using 0.1m long wires.

B) V=9V connected to R=10Ω using 0.1m long wires.

C) V=9V connected to R=1Ω using 1m long wires.

D) V=9V connected to R=10Ω using 1m long wires.

E) All are the same



Neglect the fact that, technically, more time is required to circulate around 1 m long wires compared to 0.1 m long wires

If V=12 V, R_1=6Ω, R_2=12Ω and R_3=24Ω, then $V_2(t=0)/V_2(t\rightarrow\text{infty})$=

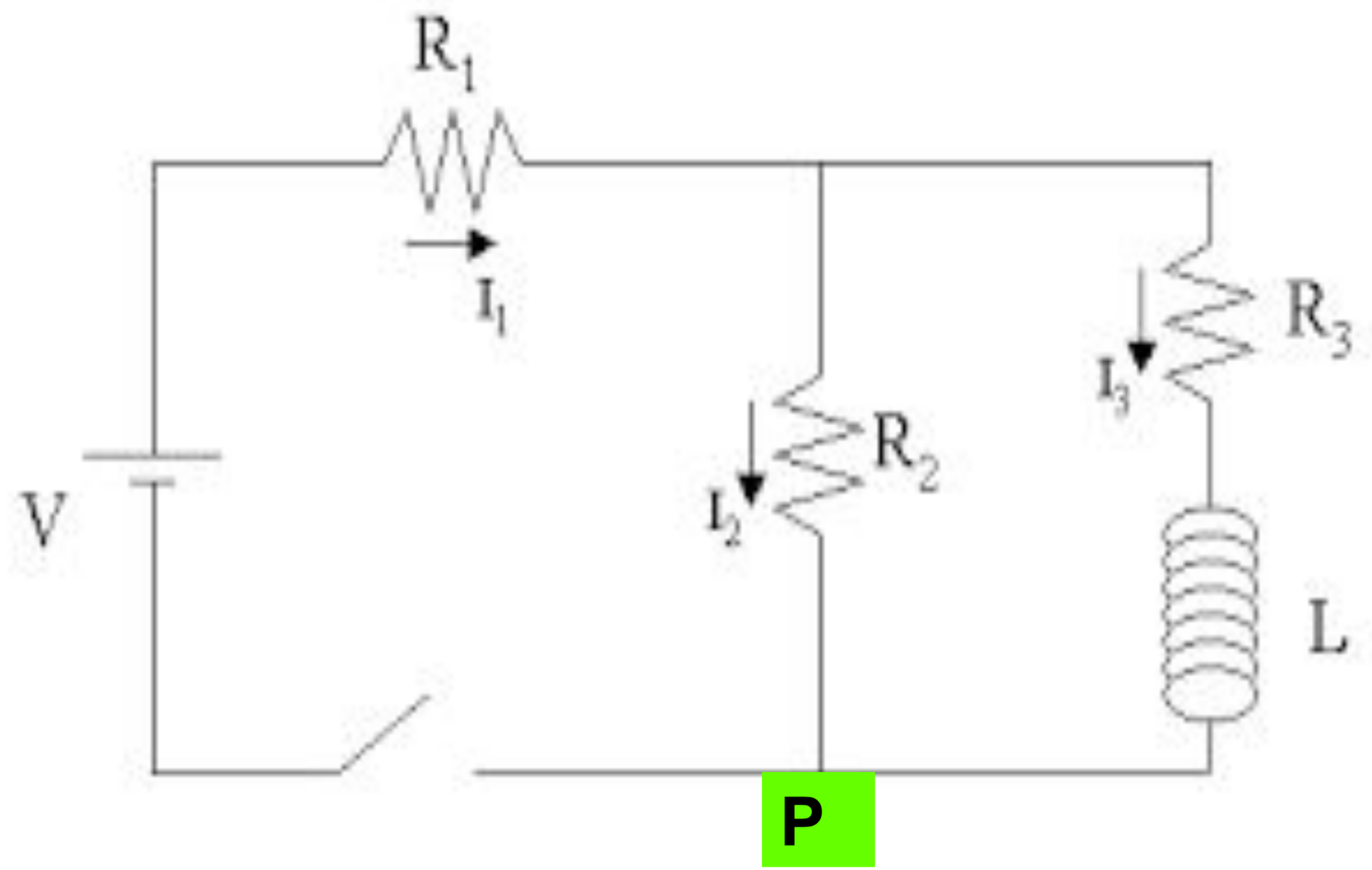
A) 2/3

B) 1.5

C) 1.167

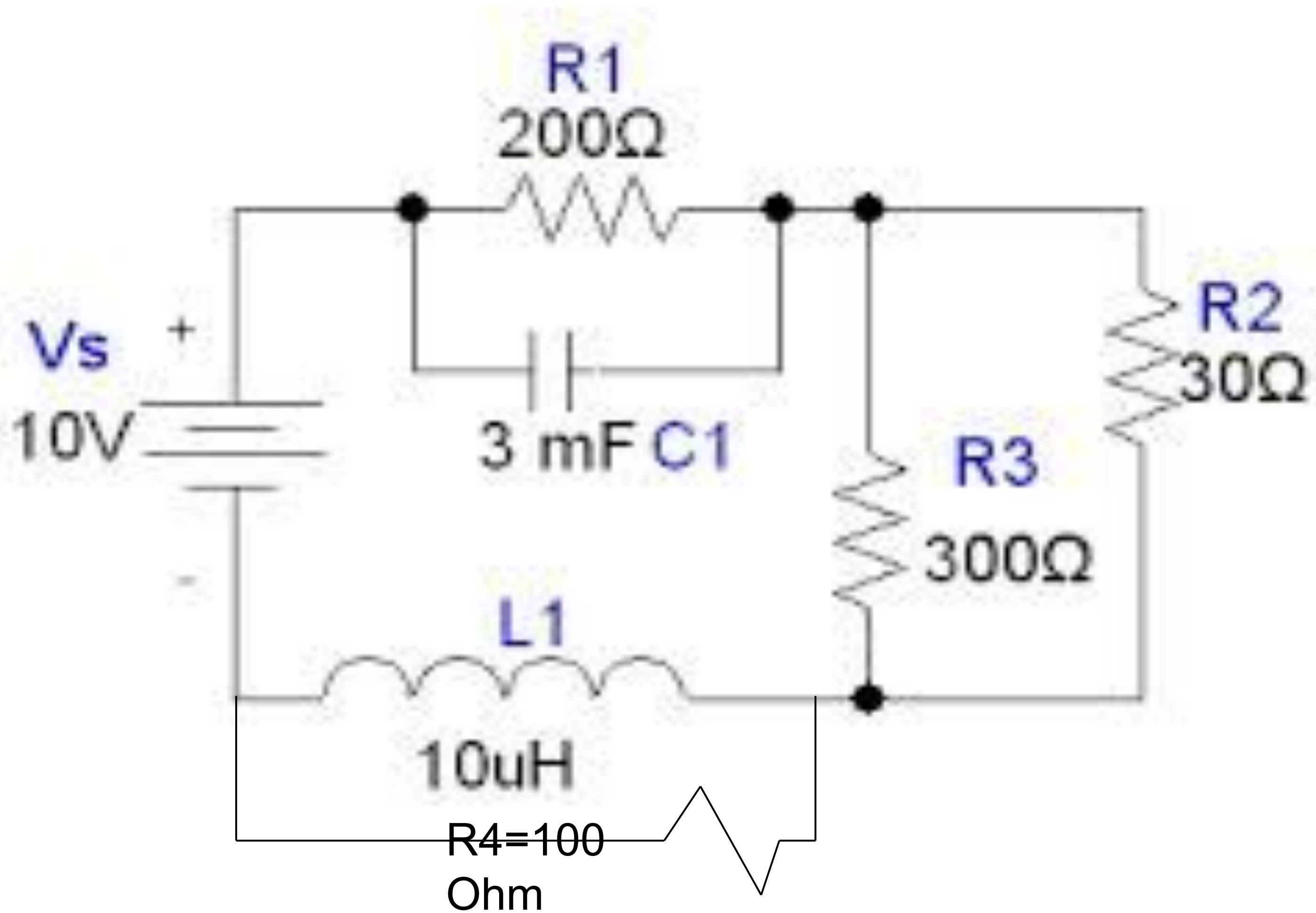
D) 0.857

E) NOTA

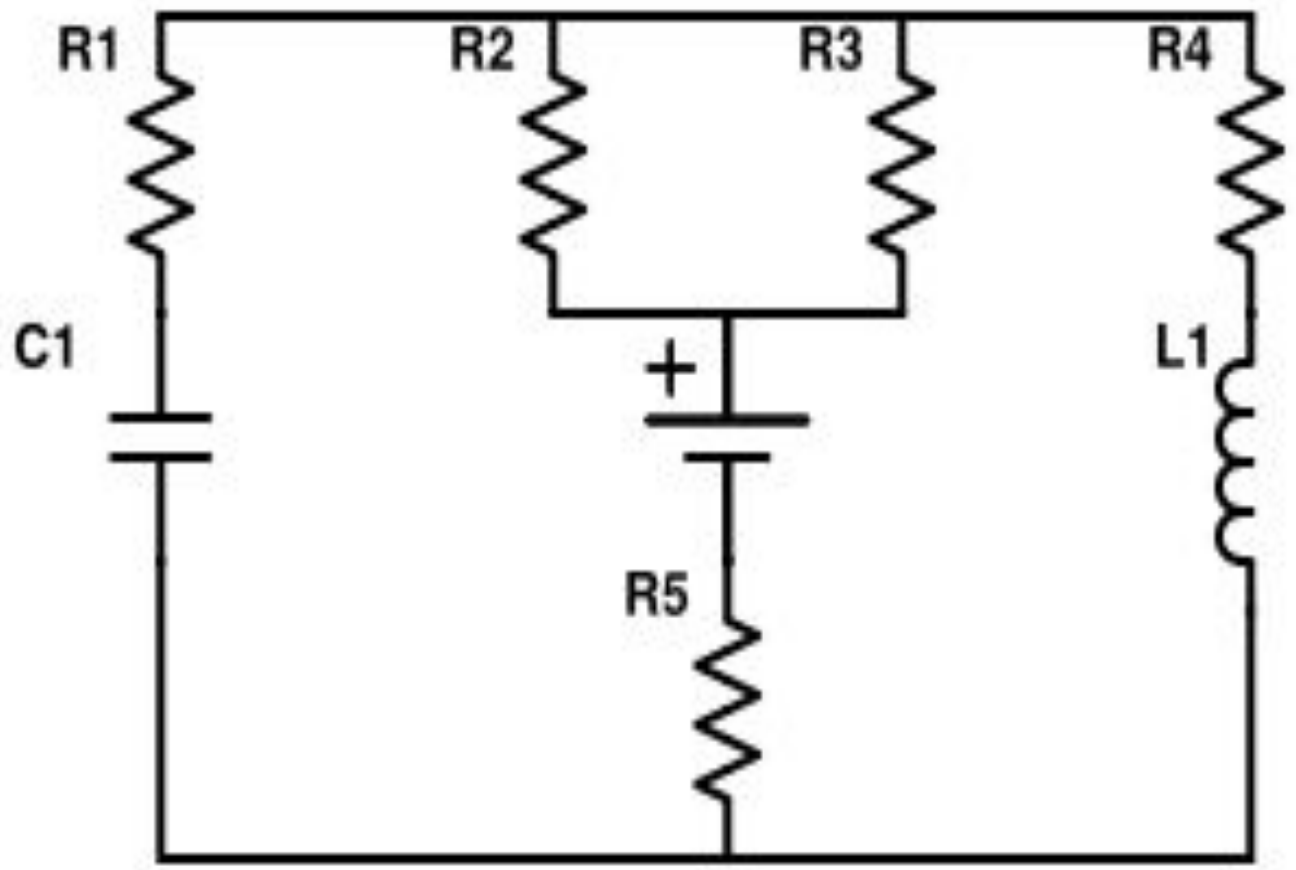


Comparing t=0 to t→infty, which statement is true?

A) $V_{2,0} < V_{2,infinity}$
B) $V_{3,0} < V_{3,infinity}$
C) $V_{L1,0} < V_{L1,infin}$
D) Two of the above
E) NOTA



Given: R_1=6 Ω, R_2=6 Ω, R_3=12 Ω, R_4=12 Ω, R_5=2 Ω, C_4=2F, V=36 V; V_{L1}(t=0)=?



A) 3 V
B) 6 V
C) 9 V
D) 18 V
E) NOTA

Given: R_1=6 Ω, R_2=6 Ω, R_3=12 Ω, R_4=12 Ω, R_5=2 Ω, C_4=2F, V=36 V; Q_{C1}(t→infty)=?

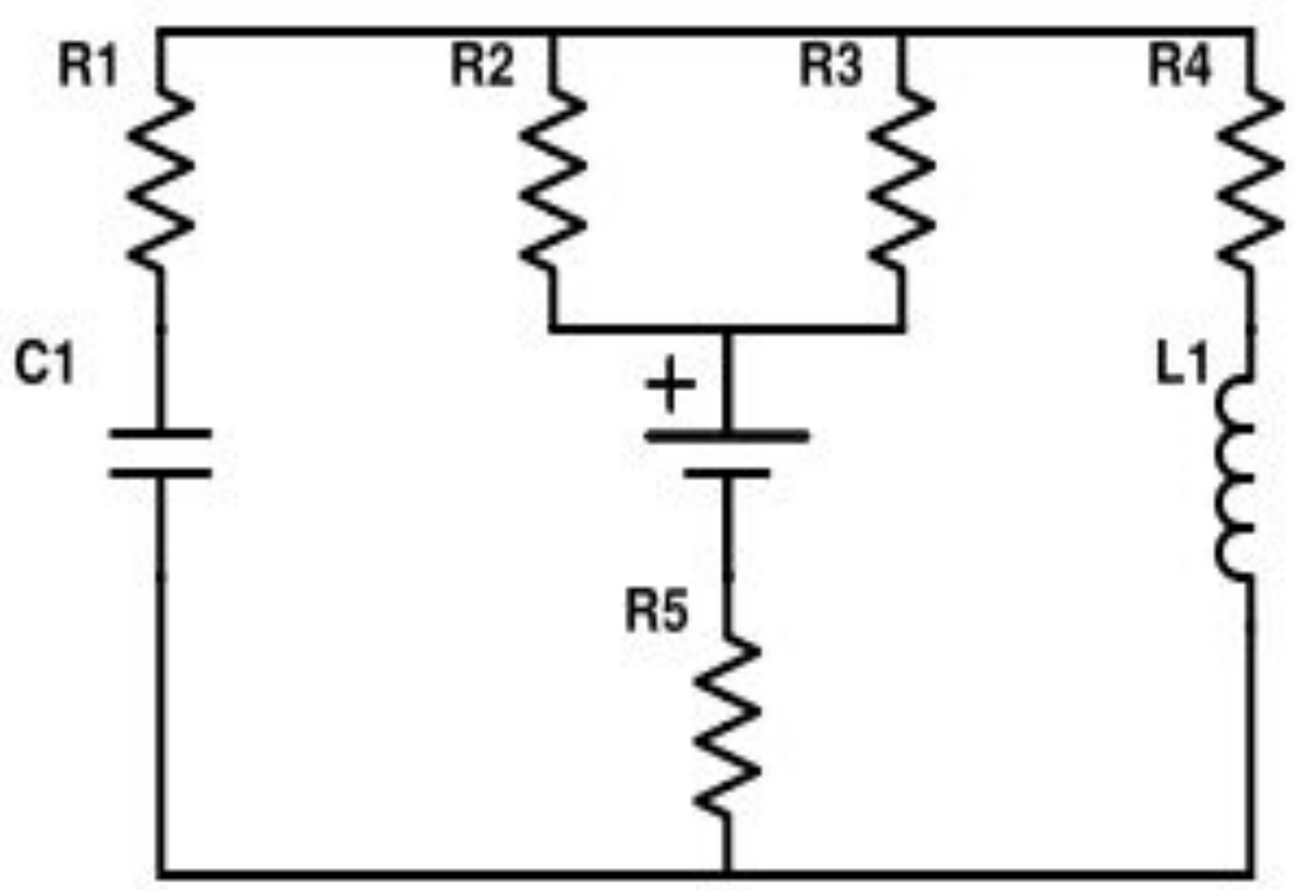
A) 8 C

B) 16 C

C) 24 C

D) 48 C

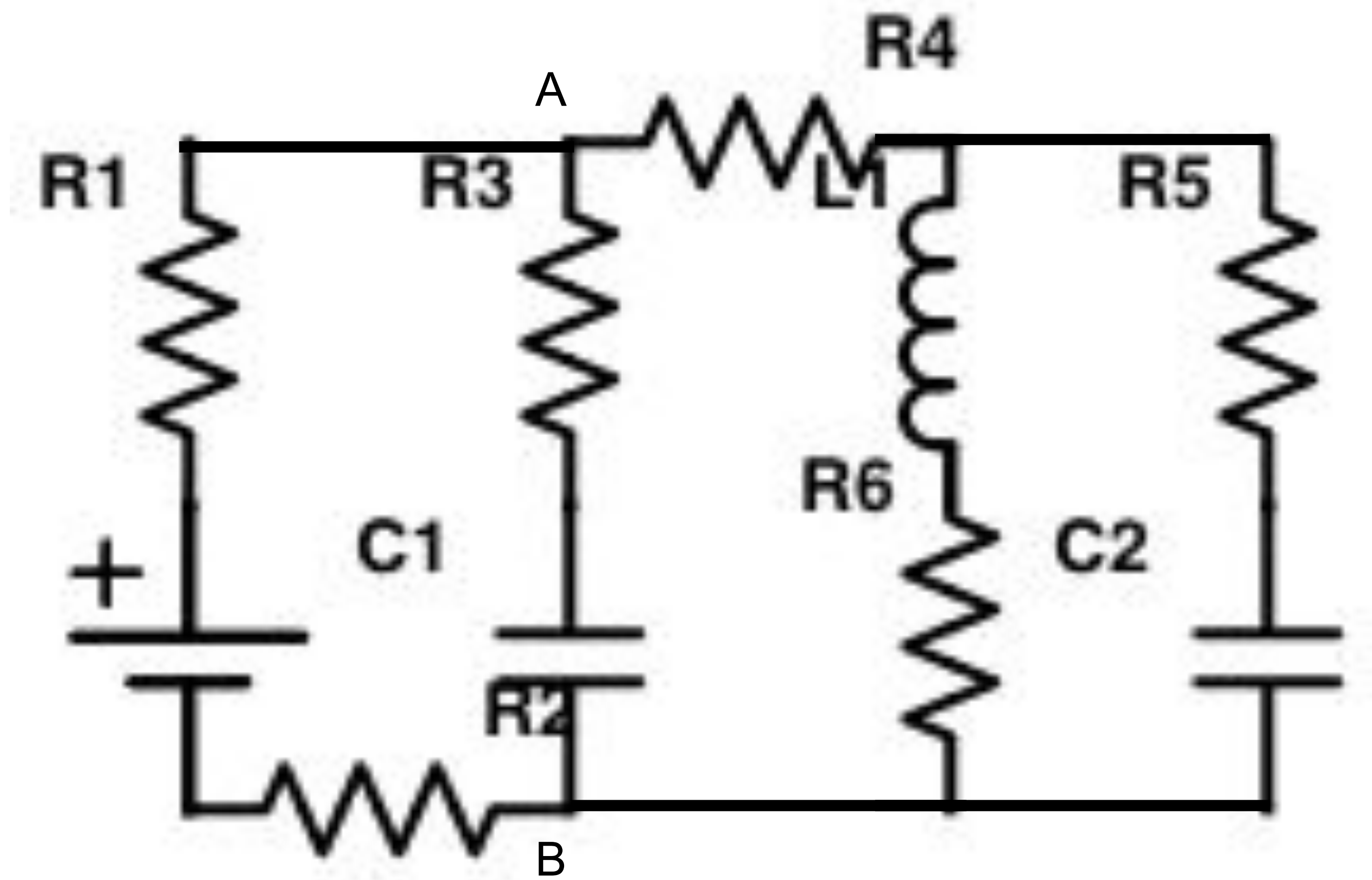
E) NOTA



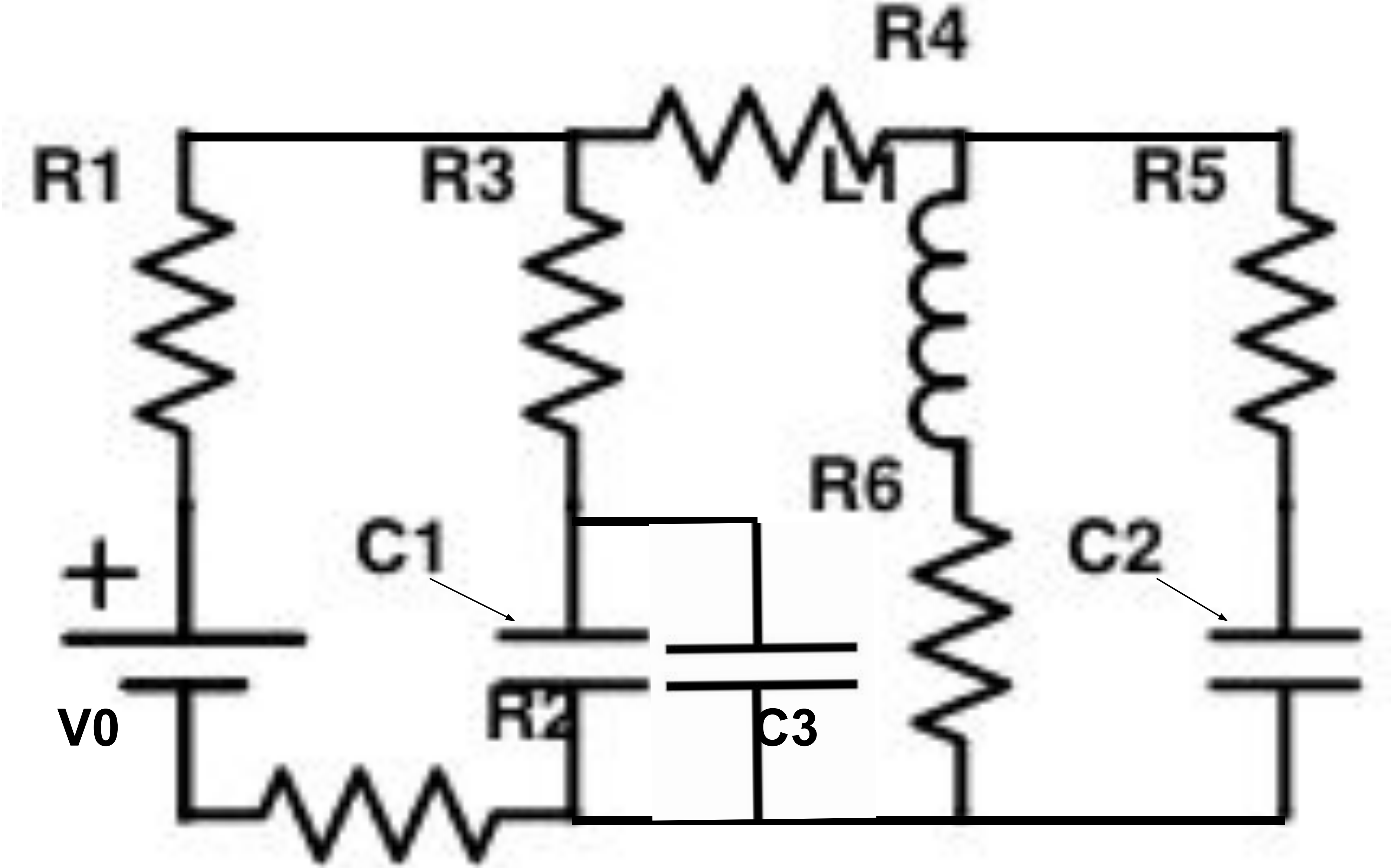
If all resistors have $R=24\Omega$, $C_1=C_2=4F$ and $L=2H$, then $V_1(t=0)/V_1(t\rightarrow\text{infty})=$

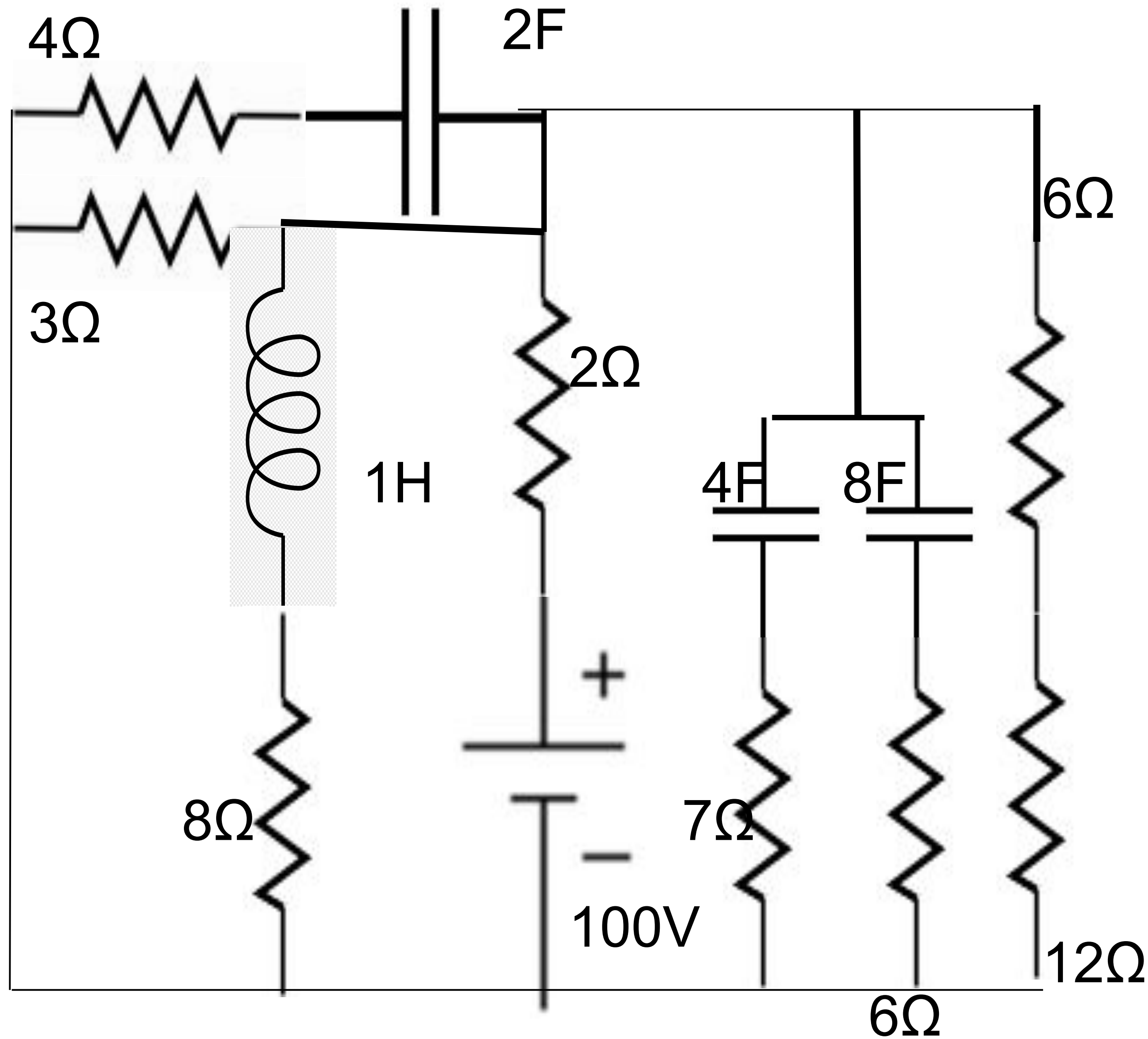
A) 1.0
B) 2/3
C) 3/2
D) 2.0
E) NOTA

V=128V



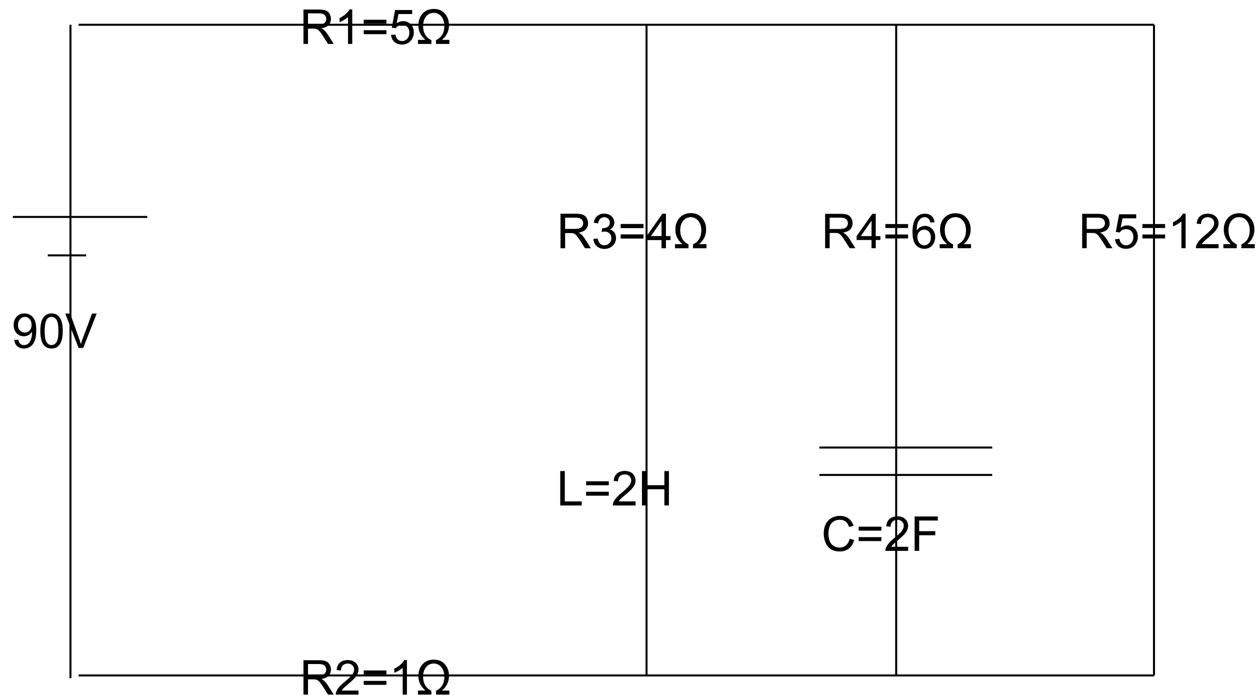
R1=2; R2=4; R3=8; R4=8; R6=R5=12. V0=100 V, C1=2F=C2; C3=4F.





4Ω
2F
6Ω
3Ω
2Ω
1H
4F
8F
+
8Ω
7Ω
–
100V
12Ω
6Ω

T=0: C has no effect; inductor blocks current through its branch: R_{tot}=10Ω=>I_{tot}=9A.
ΔV_1=45V; ΔV_2=9V; ΔV_3=0; ΔV_L=36V=ΔV_4=ΔV_5
t→infinity: L has no effect; Capacitor blocks current through its branch:
R_{tot}=9Ω=>I_{tot}=10A
ΔV_1=50V; ΔV_2=10V; ΔV_L=V_4=0 ΔV_3=30V=ΔV_C=ΔV_5, so Charge on Capacitor=60C



In the circuit below, what is the current $I_{tot}(t=0)$ and also $t \rightarrow$ infty?

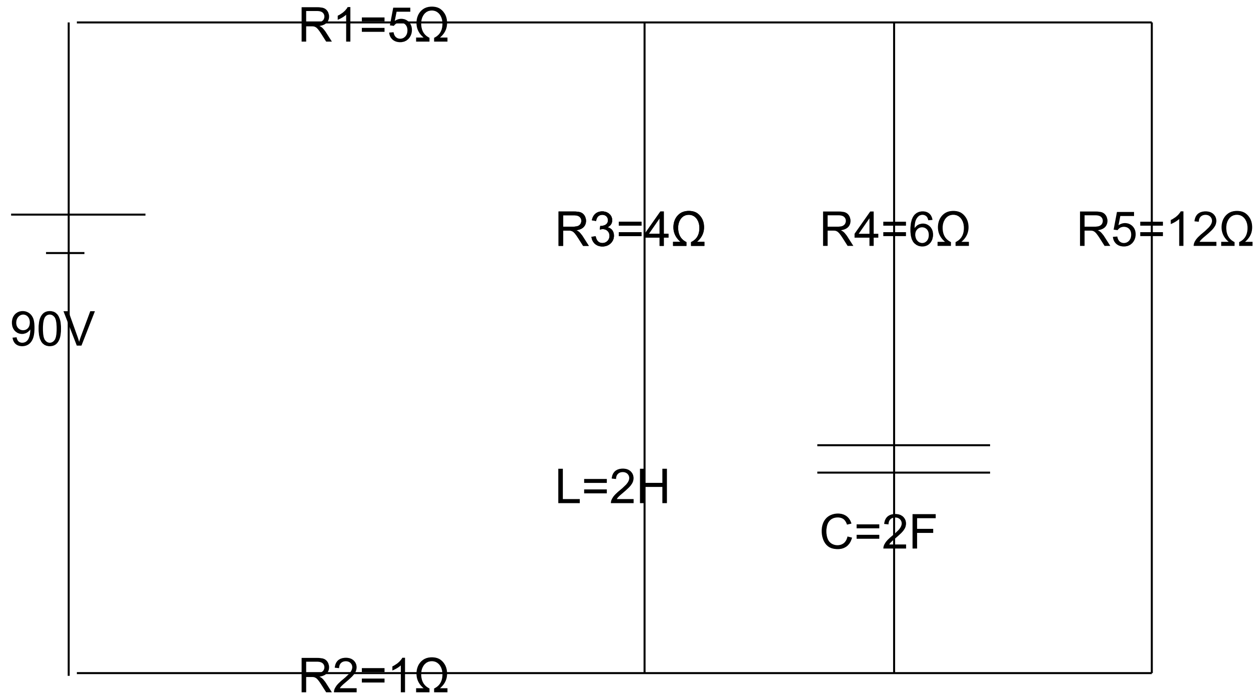
A) 9A, 10A

B) 10A, 9A

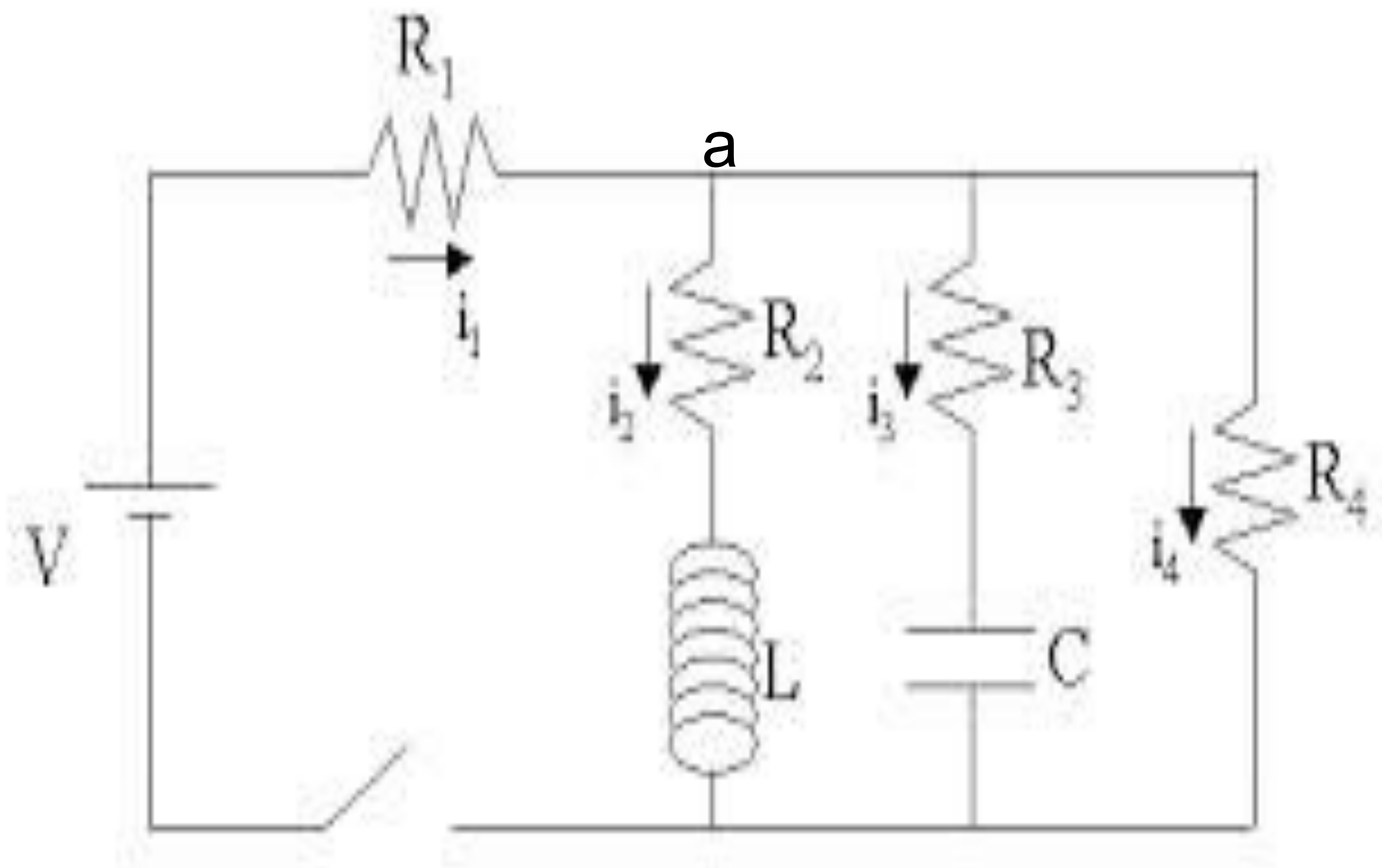
C) 8A, 8A

D) 9A, 9A

E) NOTA



Write Kirchoff's laws for junction a and the outer and middle loops.



Which of the following would you expect to be the correct formula for the resonant frequency in an RLC circuit?

A) Frequency~1/(LC)

B) Frequency~L/C

C) Frequency~C/L

D) Frequency~LC

Given an RLC circuit with L=0.2 Henries and C=0.4 Farads, being driven at a frequency of 2 Hz. To bring the circuit closer to resonance, you would:

A) Add a capacitor in series with the existing capacitor
B) Add a capacitor in parallel with the existing capacitor

In the analogy with a 'driven' mechanical oscillator, which eqn. makes `sense' for ω?

A) $\omega \sim km$
B) $\omega \sim k/m$
C) $\omega \sim m/k$
D) $\omega \sim 1/(km)$

Electromagnetic Radiation:

E_{rad}=kqa(sinθ)/c^2r; θ=angle(a,r)

E_{rad} always perpendicular to k=> perp to $E_{coulomb}$ and in direction of current constituted by source motion

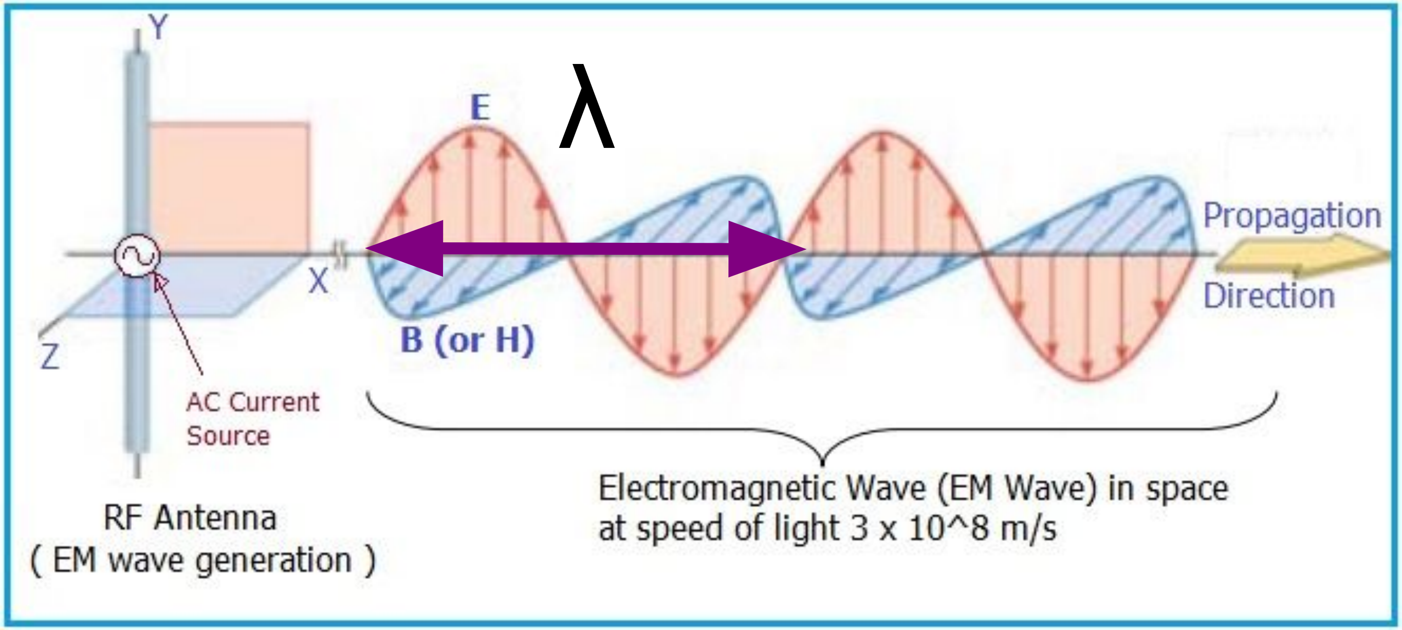
E_{rad} is vector, so add as vectors

(case of multiple sources, e.g.)

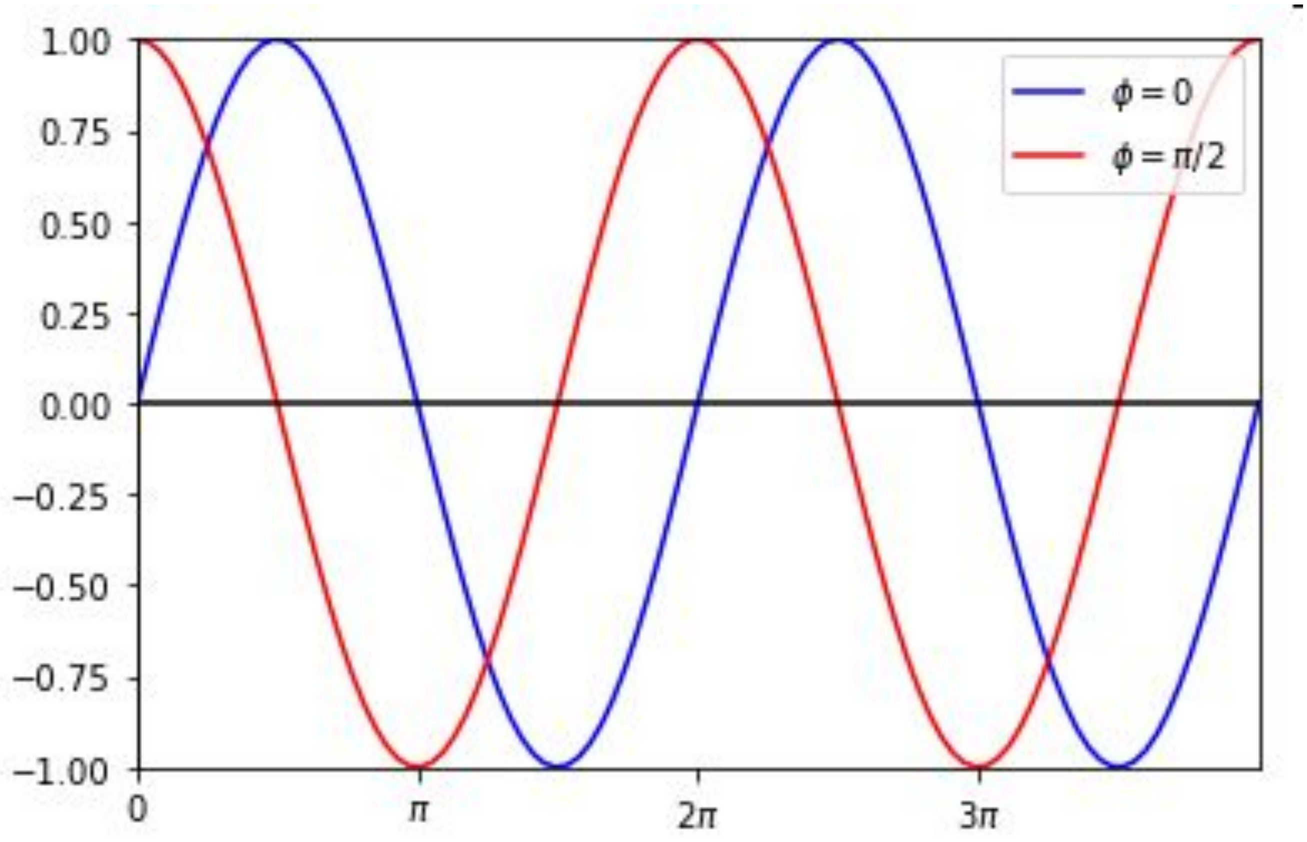
c=velocity of light in vacuum & is limit to information transfer (N.B: EPR paradox!)

|B_{rad}| =|E_{rad}/c|; B direction given by k **X** E - check directions: E x B=k?

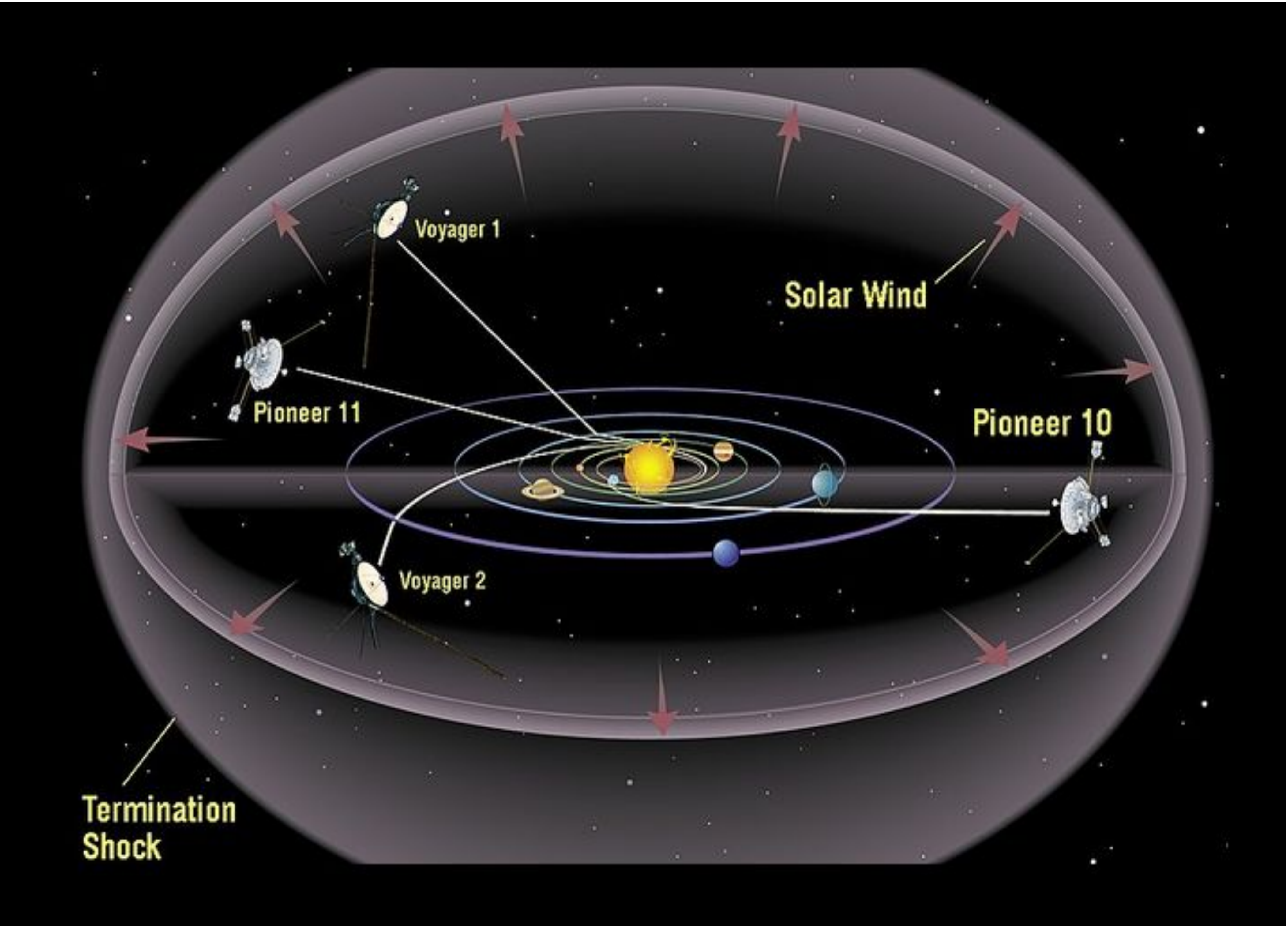
S [Energy/m^2/sec=W/m^2] =$E_{rad}{}^2/2Z_0 \sim E_{rad}{}^2/240\pi$

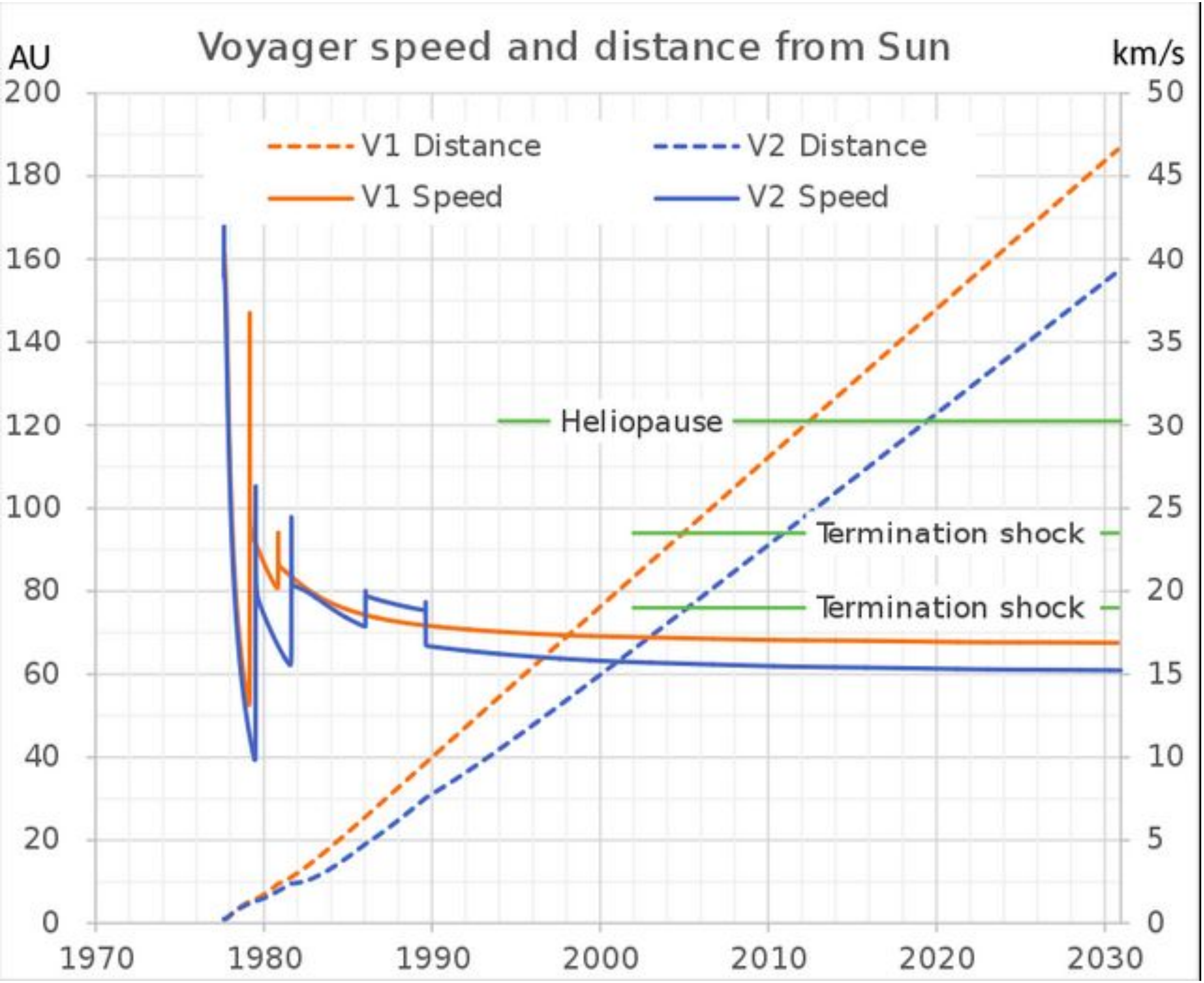


Y
λ
E
Propagation
Direction
X
Z
B (or H)
AC Current
Source
Electromagnetic Wave (EM Wave) in space
at speed of light 3 x 10^8 m/s
RF Antenna
(EM wave generation)



1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
0
π
2π
3π
ϕ = 0
ϕ = π/2


Voyager 1
Solar Wind
Pioneer 11
Pioneer 10
Voyager 2
Termination
Shock



Voyager speed and distance from Sun
AU
km/s
V1 Distance
V2 Distance
V1 Speed
V2 Speed
Heliopause
Termination shock
Termination shock
200
180
160
140
120
100
80
60
40
20
0
50
45
40
35
30
25
20
15
10
5
0
1970
1980
1990
2000
2010
2020
2030

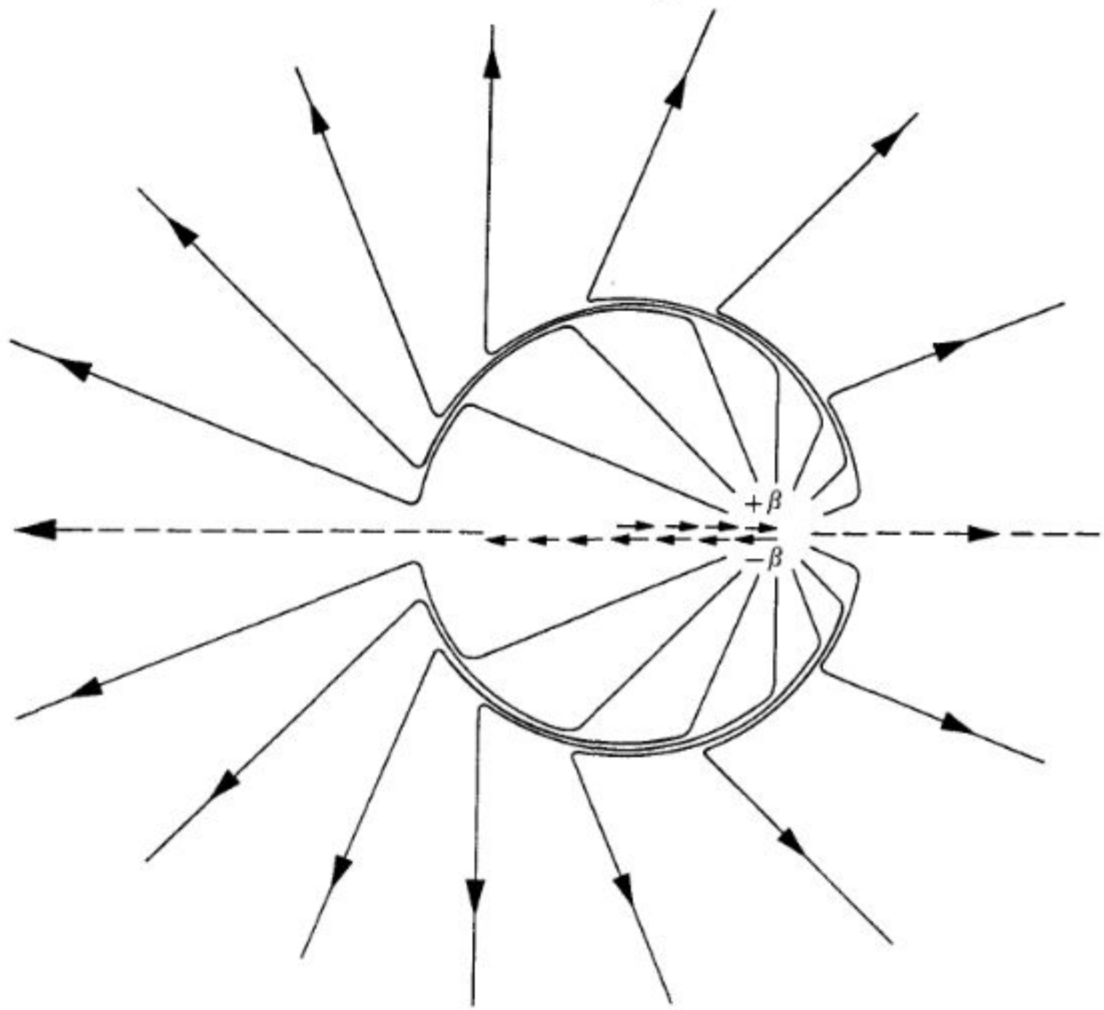


Figure 4.6.
Mechanism of radiation. J. J. Thomson's way to understand why the strength of an electromagnetic wave falls only as the inverse first power of distance r and why the amplitude of the wave varies (for low velocities) as $\sin\theta$ (maximum in the plane perpendicular to the line of acceleration). The charge was moving to the left at uniform velocity. Far away from it, the lines of force continue to move as if this uniform velocity were going to continue forever (Coulomb field of point-charge in slow motion). However, closer up the field is that of a point-change moving to the right with uniform velocity ($1/r^2$ dependence of strength upon distance). The change from the one field pattern to another is confined to a shell of thickness $\Delta\tau$ located at a distance r from the point of acceleration (amplification of field by "stretching factor" $r\sin\theta\ \Delta\beta/\Delta\tau$; see text). We thank C. Teitelboim for the construction of this diagram.

A -0.4 C, 2 gram charge at (0,0) feels a force F_y=100 N, as a result of which it accelerates and begins radiating. The produced E_{rad}(800 m,0)=

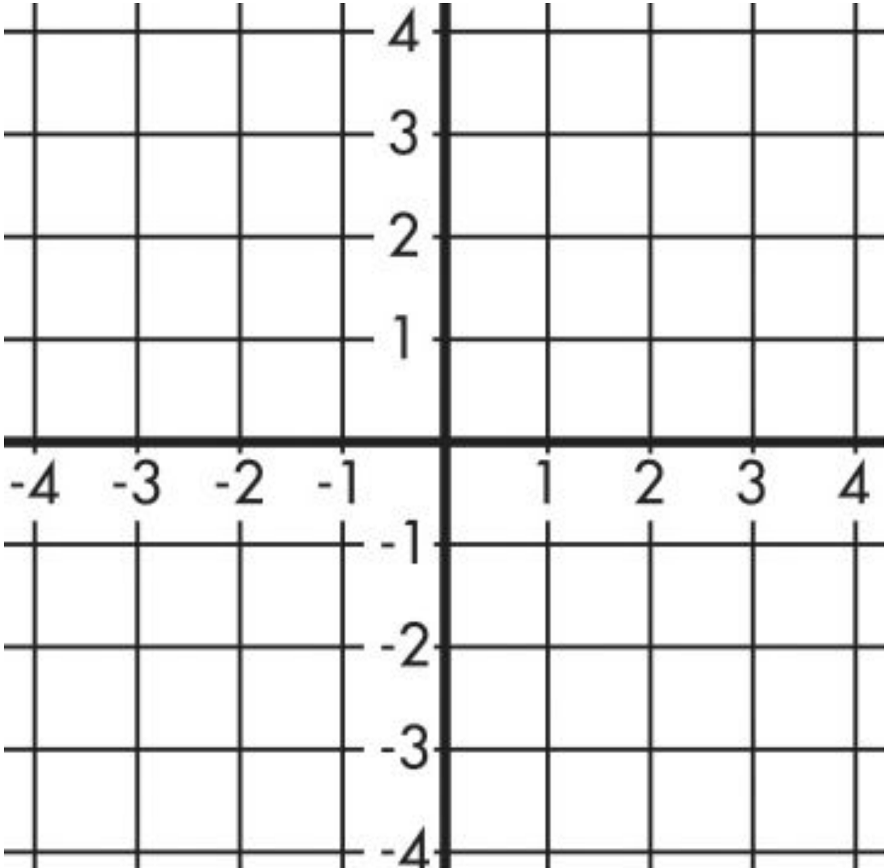
A) 2.5×10^{-2} N/C (+y)

B) 2.5×10^{-3} N/C (+y)

C) 2.5×10^{-5} N/C (-y)

D) 2.5×10^{-6} N/C (-y)

E) NOTA



The directions of B_{rad} at (800,0), (-800,0) and (0,800), respectively, are:

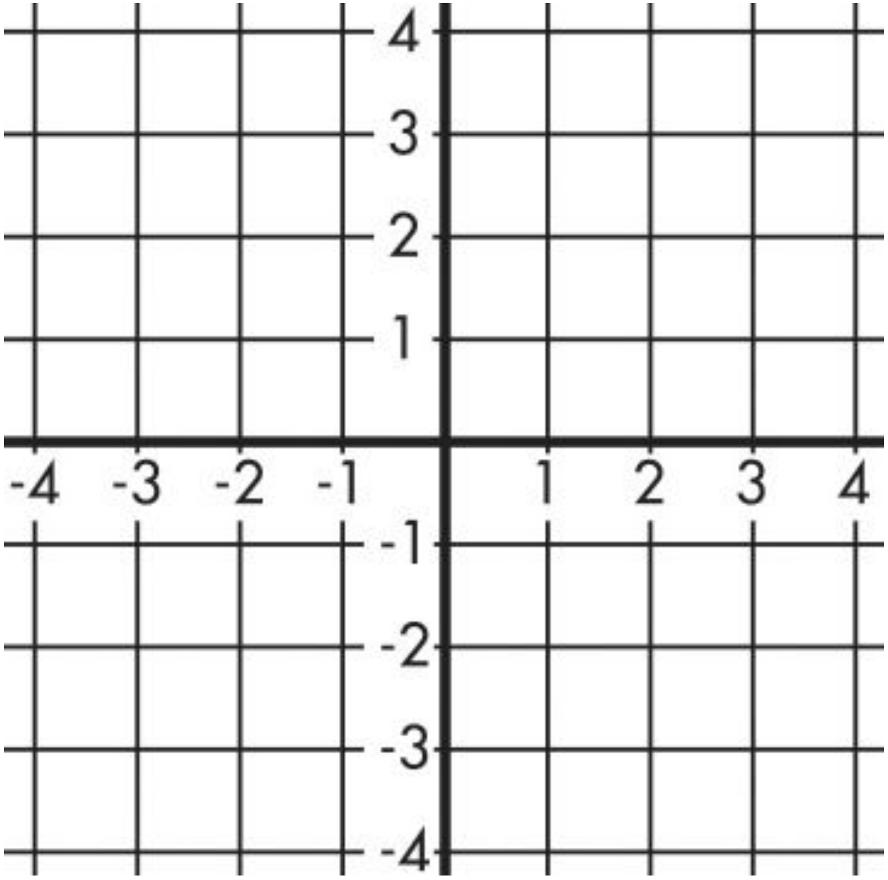
A) +z, -z, 0

B) -z, +z, 0

C) +x, -x, 0

D) -x, +x, 0

E) NOTA



A 0.8 C, 4 g charge at (0,0) feels a force F_y=200 N. E_{rad}(1200 m, 1600 m)=

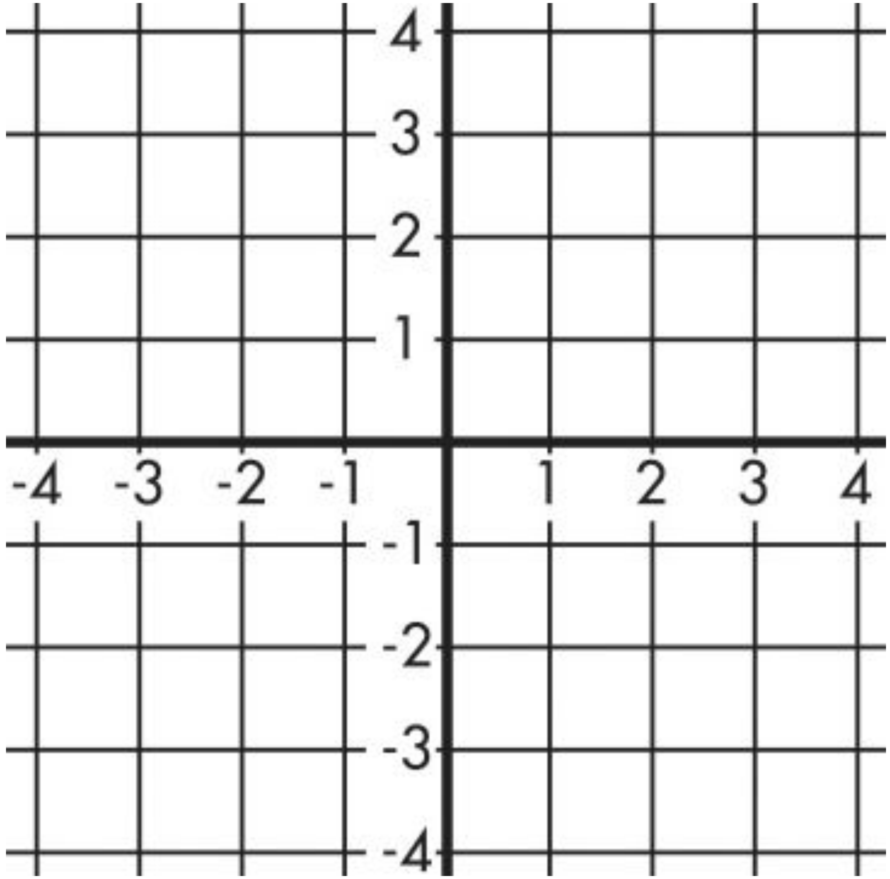
A) 1.5×10^{-2} N/C

B) 1.5×10^{-3} N/C

C) 1.2×10^{-6} N/C

D) 6×10^{-7} N/C

E) NOTA



The average current I=Δq/Δt, after the charge has moved 1 mm, is:

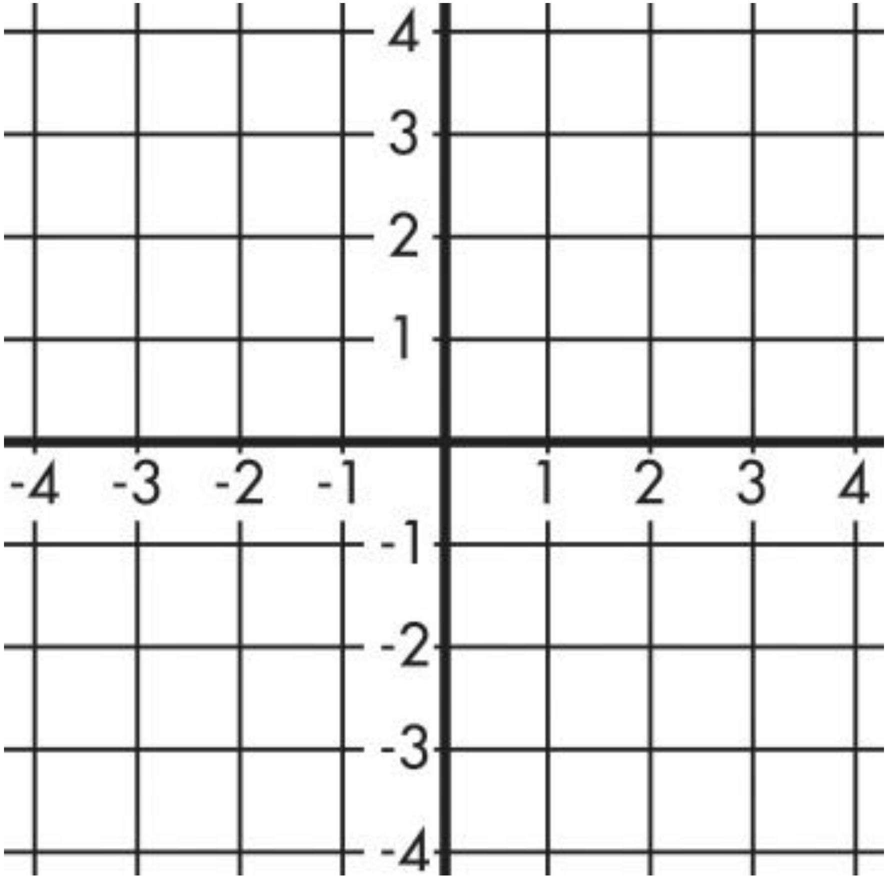
A) 2 mA

B) 0.2 mA

C) 4 mA

D) 4000 A

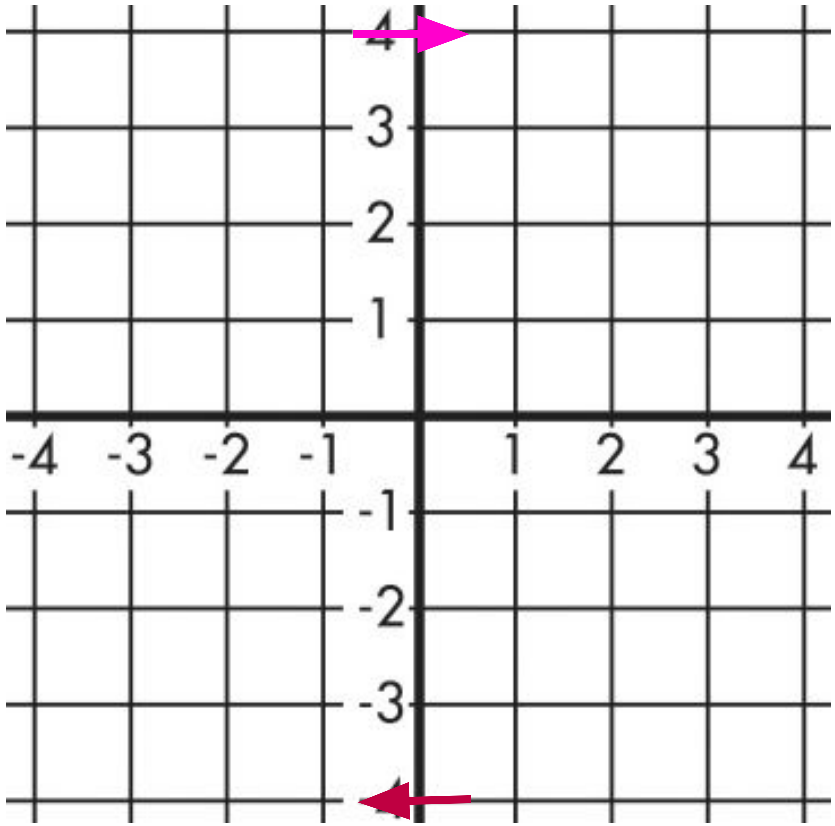
E) NOTA




Soy la
pera

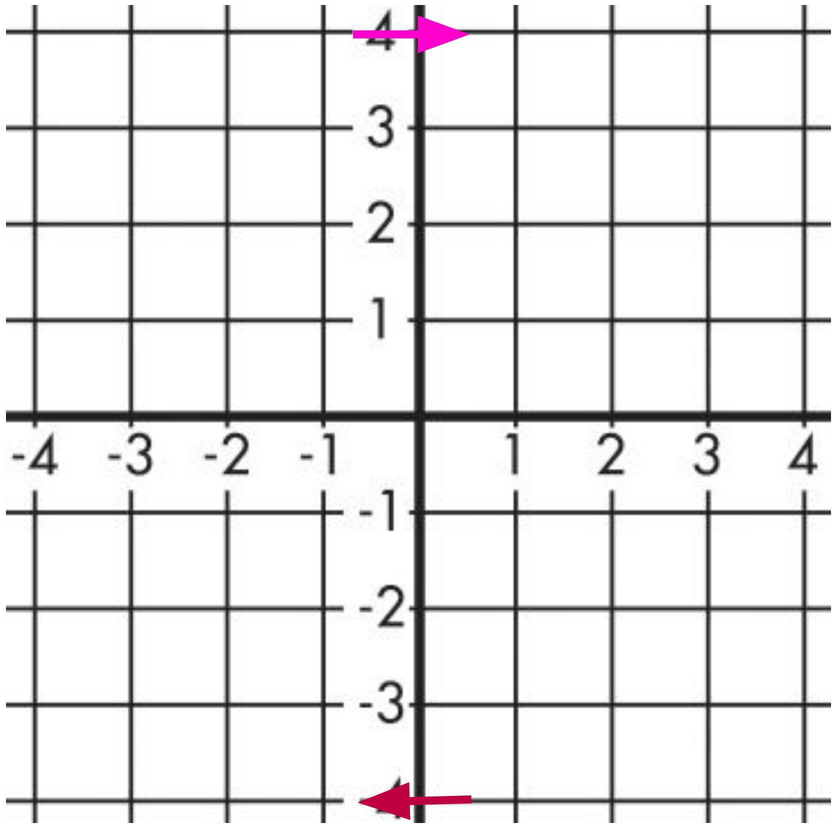
A -1C charge accelerates in +x at (0,4m); a +1C charge has the same magnitude acceleration, in -x at (x,y)=(0,-4m). A negative test charge at the origin will accelerate in which direction, under the influence of the net radiation electric field at the origin?

A) +x
B) +y
C) -x
D) -y
E) NOTA or $E_{net,rad}$~0



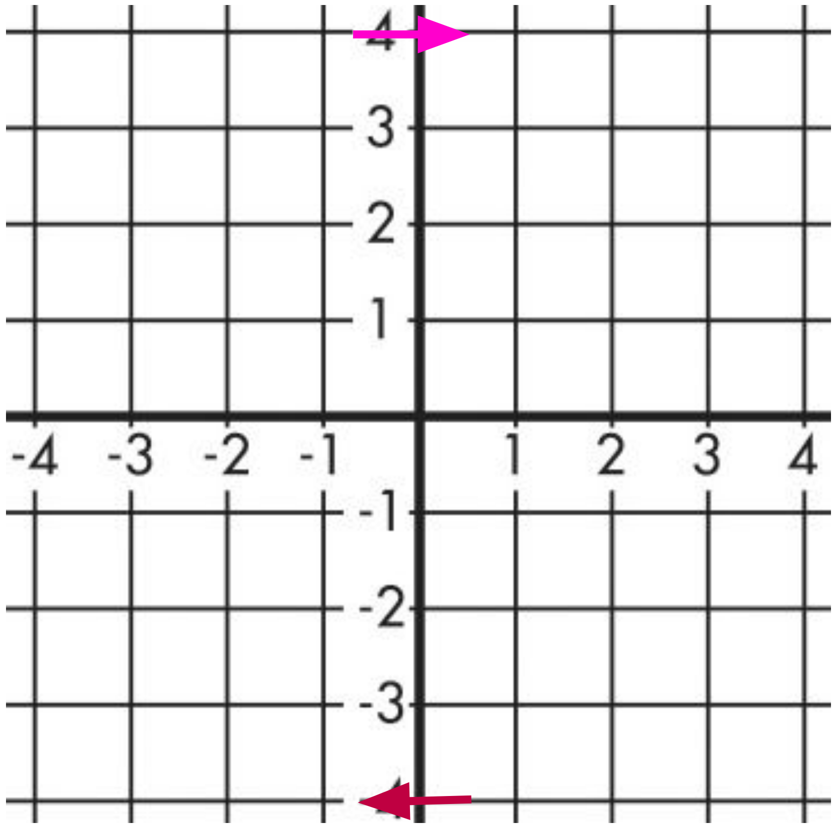
A -1C charge accelerates in +x at (0,4m); a +1C charge has the same magnitude acceleration, in -x at (x,y)=(0,-4m). The net radiation magnetic field at the origin points in

A) +x
B) +y
C) -x
D) -y
E) NOTA or $B_{net,rad}$~0



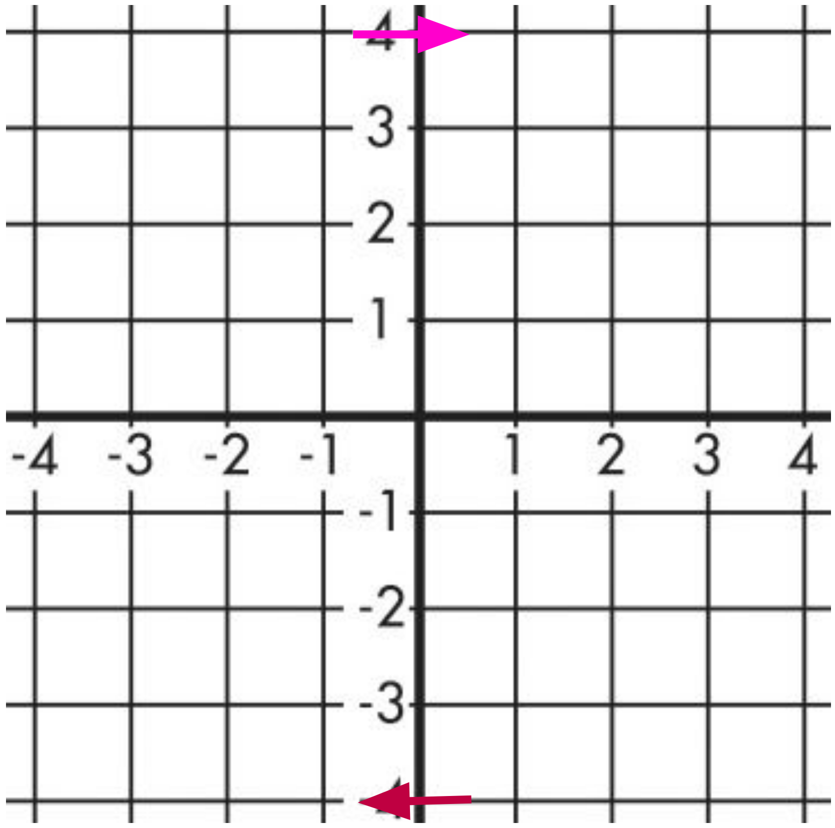
A -1C charge accelerates in +x at (0,4m); a +1C charge has the same magnitude acceleration, in -x at (x,y)=(0,-4m). The net static electric field at the origin points in

A) +x
B) +y
C) -x
D) -y
E) NOTA or $E_{net,static} \sim 0$



A -1C charge accelerates in +x at (0,4m); a +1C charge has the same magnitude acceleration, in -x at (x,y)=(0,-4m). The net current magnetic field at the origin points in

A) +x
B) +y
C) -x
D) -y
E) NOTA or $B_{net,current}$~0



Given that $E_{rad} = kqa\sin\theta/c^2r$, the acceleration needed such that E_{rad} from a source at the origin, measured at r=100 m equals $E_{Coulomb}$

A) 10^3 g

B) 10^4 g

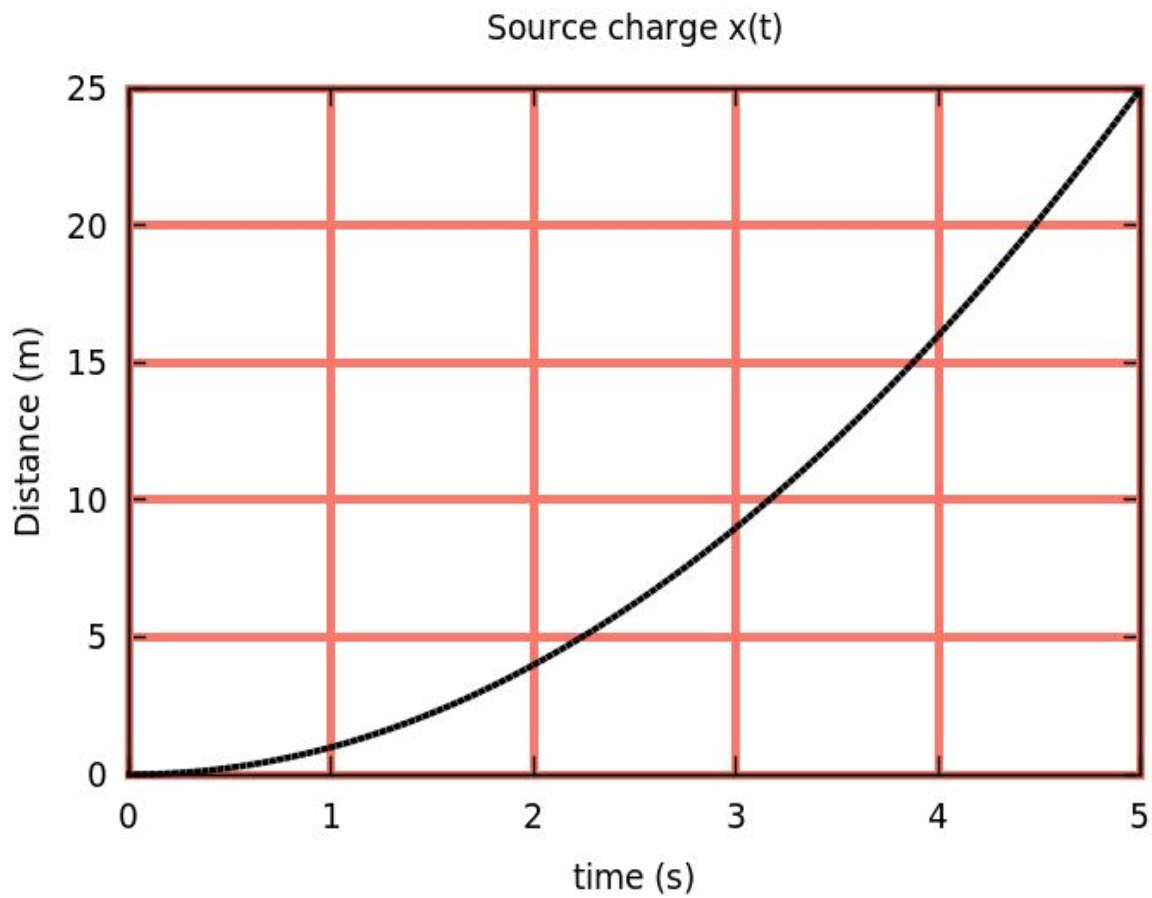
C) 10^5 g

D) 10^9 g

E) 10^{15} g

Given the x(t) graph for a 0.1 C source charge, rank the $E_{Coulomb}$, $B_{current}$, E_{rad}, and B_{rad} fields at a distance of 2 km

A) $E_C > B_c > E_r > B_r$
B) $E_r > B_r > E_C > B_c$
C) $E_C < B_c < E_r < B_r$
D) NOTA



A 2 C charge accelerates in +x for 10^{-6} seconds at 10^6 g; F_{net} on a stationary 0.1 C test charge at (x,y)=(0,10^7 km)= ($k=9\times10^9$ N-m^2/C^2)

A) 1.8×10^{-11} N

B) 1.96×10^{-11} N

C) 2.66×10^{-11} N

D) NOTA

The direction of F_{net} is:

$B_{current}$ after the charge has moved 1 mm, is (assume it starts from rest):

A) 0.16k' T

B) 1.6k' T

C) 2k' T

D) 2 x 10^{-5}k' T

E) NOTA

If the 0.1 C test charge moves at 0.2c, then $F_{net, magnetic}$ on the charge is:

A) 10.5 N

B) 0.00024 N

C) 0.1 N

D) 3×10^{-13} N

E) NOTA

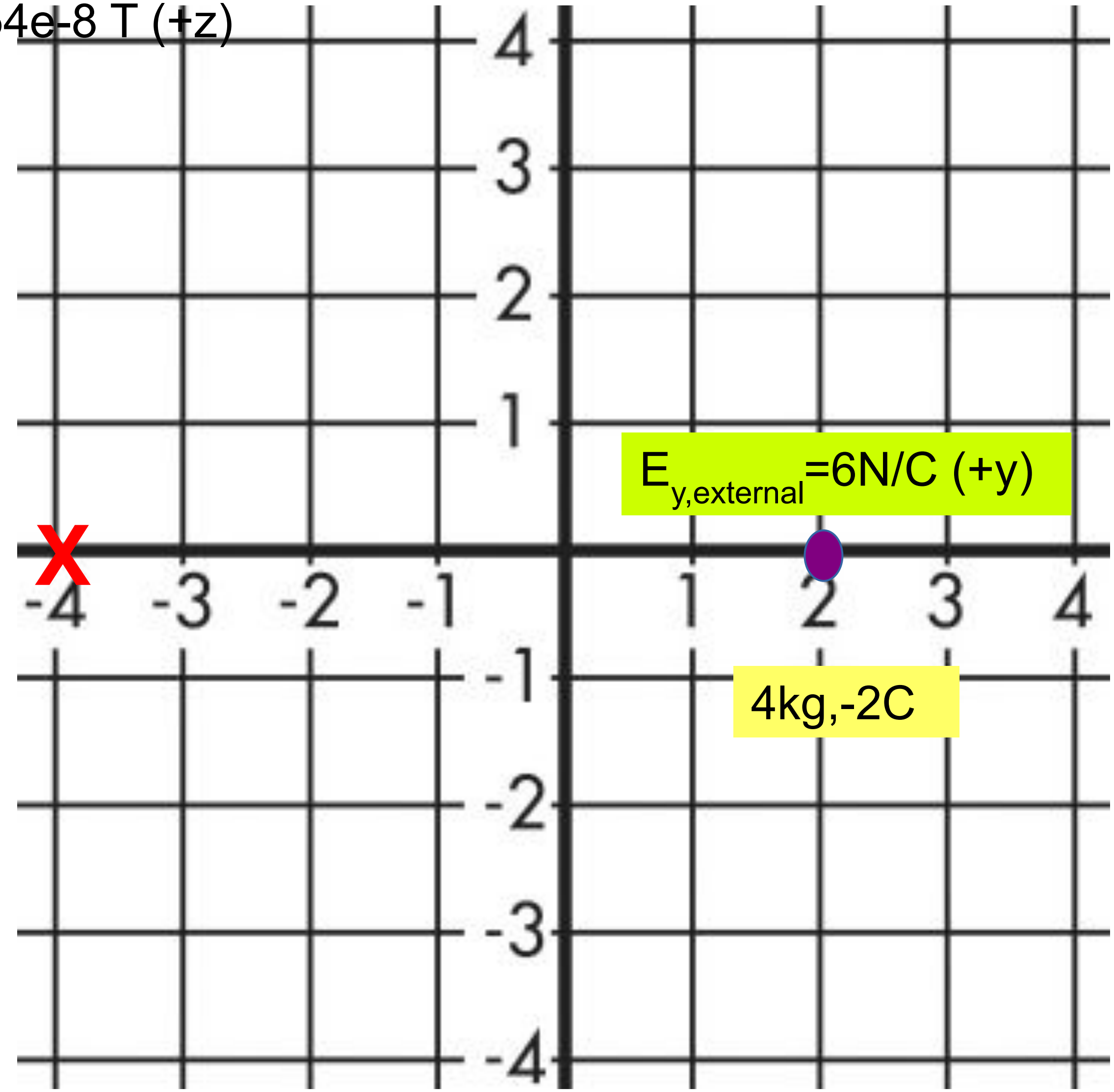
A 4 kg, -2 C charged particle is located at the point (2m,0); it is in an E-field: 6N/C in the +y direction; as a result of the electrical force, the -2C charge moves a distance of 4 m. Determine, in sequence: i) the acceleration of the charge, ii) the time required for the charge to move the 4 m, iii) the current constituted by the charge's motion (charge divided by the time you just calculated). iv) From your answer to i), determine E_{rad} (magnitude and direction) at the measurement point (-4m,0), as well as B_{rad} (magnitude and direction) at the same point. As a reminder, the magnitude of $B_{rad}=E_{rad}/c$ (see sect. 24.2 from the online text). v) from your answer to iii), calculate $B_{current}$ (magnitude and direction) at the same measurement point (0,4m).

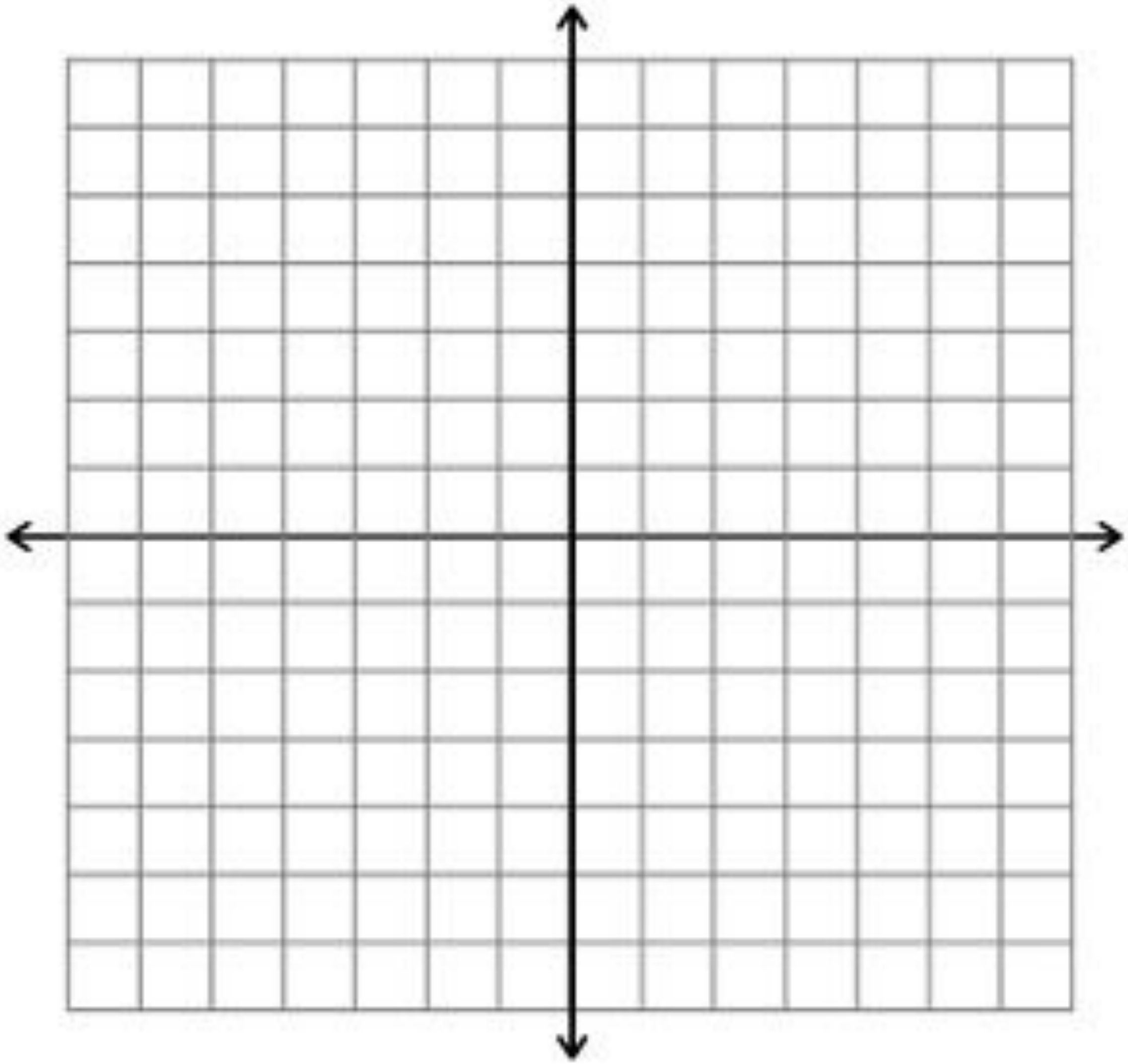
$a=F/m=12N/4kg = 3m/s^2$ (-y); t to travel 4 m from $y_f=y_i+v_{i,y}t+ \frac{1}{2}at^2$ (ignore gravity), so t=1.64 s; current I=q*x/t=(2C/1.64s) (+y) / What is $E_{rad}(-4m,0)$ due to initial acceleration?

$E_{rad}=kqa(\sin\theta/c^2r)$: θ=angle b/w **a** and **r** (90^o in this case), r=vector b/w source of E_{rad} and measurement pt X (6m in this case), so E_{rad}=1e-09 N/C; $E_{rad}||a$ for positive source charge, so here in +y-direction.

$B_{rad}=E_{rad}/c$; direction given by RHR(1) – first vector=**r**; second vector=$\mathbf{E_{rad}}$, so B_{rad} in -z

$B_{current}$=k'I/r=2e-7*(2C/1.64s)/6m=4.54e-8 T (+z)





A radiation electric field, due to a charge Q (having mass m) at the origin, acted on by an *external* electric field E, is measured to be 0.0025 N/C at x=800 m. The radiation *Intensity* at x=800 m is:

A) 1.48×10^{-3} W/m^2

B) 3.34×10^{-6} W/m^2

C) 8.3×10^{-9} W/m^2

D) 2.44 W/m^2

E) NOTA

Assuming full-spherical spreading, the total amount of energy radiated by the accelerating charge, in 2 seconds, is about:

A) 0.13 J

B) 1.3 J

C) 0.013 J

D) 13 J

E) NOTA

Assuming $E_{external}$ doubled, then the amount of radiated power would:

A) Be the same

B) Double

C) Quadruple

D) Halve

E) NOTA

Assuming the charge Q and its mass both doubled, then the amount of radiated power would:

A) Be the same

B) Double

C) Quadruple

D) Halve

E) NOTA

Solar energy radiates the Earth at 1368 W/m^2; estimate the efficiency of the human eye (assume circular pupil of diameter 1 cm) if it generates a voltage of about 1 mV and a current of about 1 pA for one second.

A) 10^{-14}

B) 10^{-8}

C) 10^{-3}

D) 0.4

Estimate the energy delivered (full moon) to a 50 cm x 50 cm solar panel via moonshine in 5 seconds, knowing that the moon is about 1° in the sky, with an albedo of 0.11. P_S=1368 W/m^2)

A) 15 J

B) 0.15 J

C) 0.015 J

D) 0.0015 J

E) 0.00015 J

Standing at x=-4 m, you measure E_{rad}, in +x; you also measure $E_{coulomb}$ in +y-direction. From that and knowing $E_{rad}=kQa(\sin\theta)/c^2r$, you conclude that the source Q is:

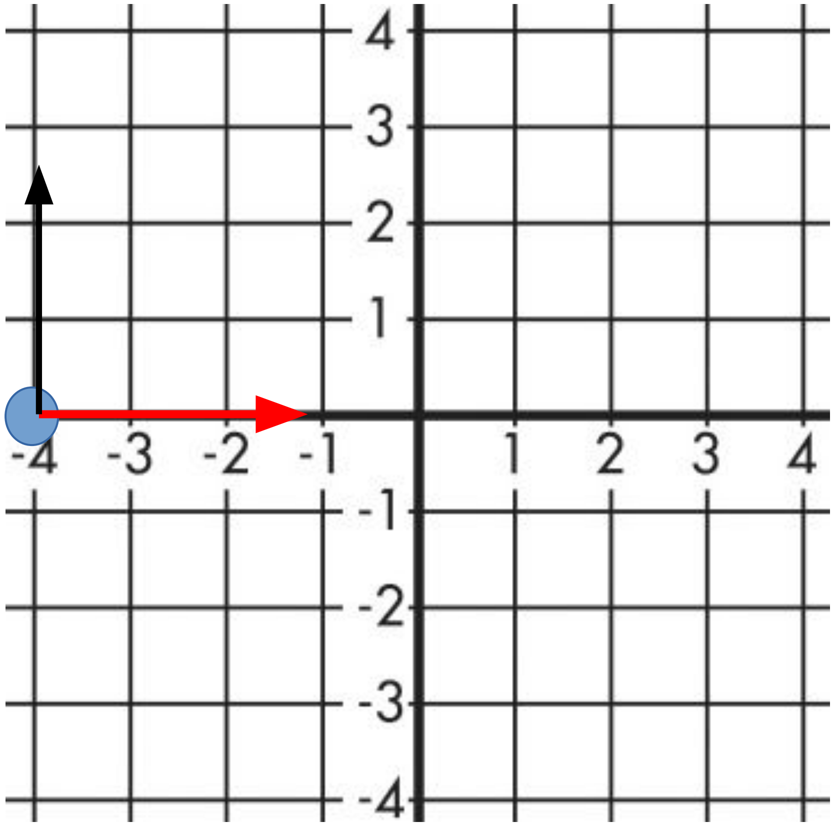
A) Negative, at y>0, and **a** in -x

B) Negative, at y<0, and **a** in +x

C) Positive, at y>0, and **a** in +x

D) Positive, at y<0 and **a** in -x

E) Two of the above



In the same problem, $B_{current}$ and B_{rad} point along:
A) +z, -z
B) +z, +z
C) -z, +z
D) -z, -z
E) NOTA

Given S_0=1368 W/m^2, and 1 W=1J/s, the total solar electromagnetic radiation energy intercepted by a solar panel 2m x 2m directly facing the sun, over a time 0.25 seconds,=

A) 1368 J

B) 2736 J

C) 684 J

D) NOTA

What is E_{rad} for solar EM radiation at the Earth given that $S=E^2/240\pi$ ($S=I_{solar}=1368$ W/m^2; $r_{Earth,Sun}=146\times10^9 m$)

A) $E_{rad}=34.3$ V/m

B) $E_{rad}=211.1$ V/m

C) $E_{rad}=1015$ V/m;

D) NOTA

What is the total solar power radiated at the source, assuming 3-d spherical spreading?

A) $P_0=3.66 \times 10^{26}$ Watts

B) $P_0=6.2$ MegaWatts

C) $P_0=7.89$ TeraWatts

D) NOTA

Suppose the sun only beamed energy into the hemisphere containing the Earth, and you measured the same I_{solar}. In that case, your estimate for the total solar power at the source, relative to the previous problem, would be

A) Smaller

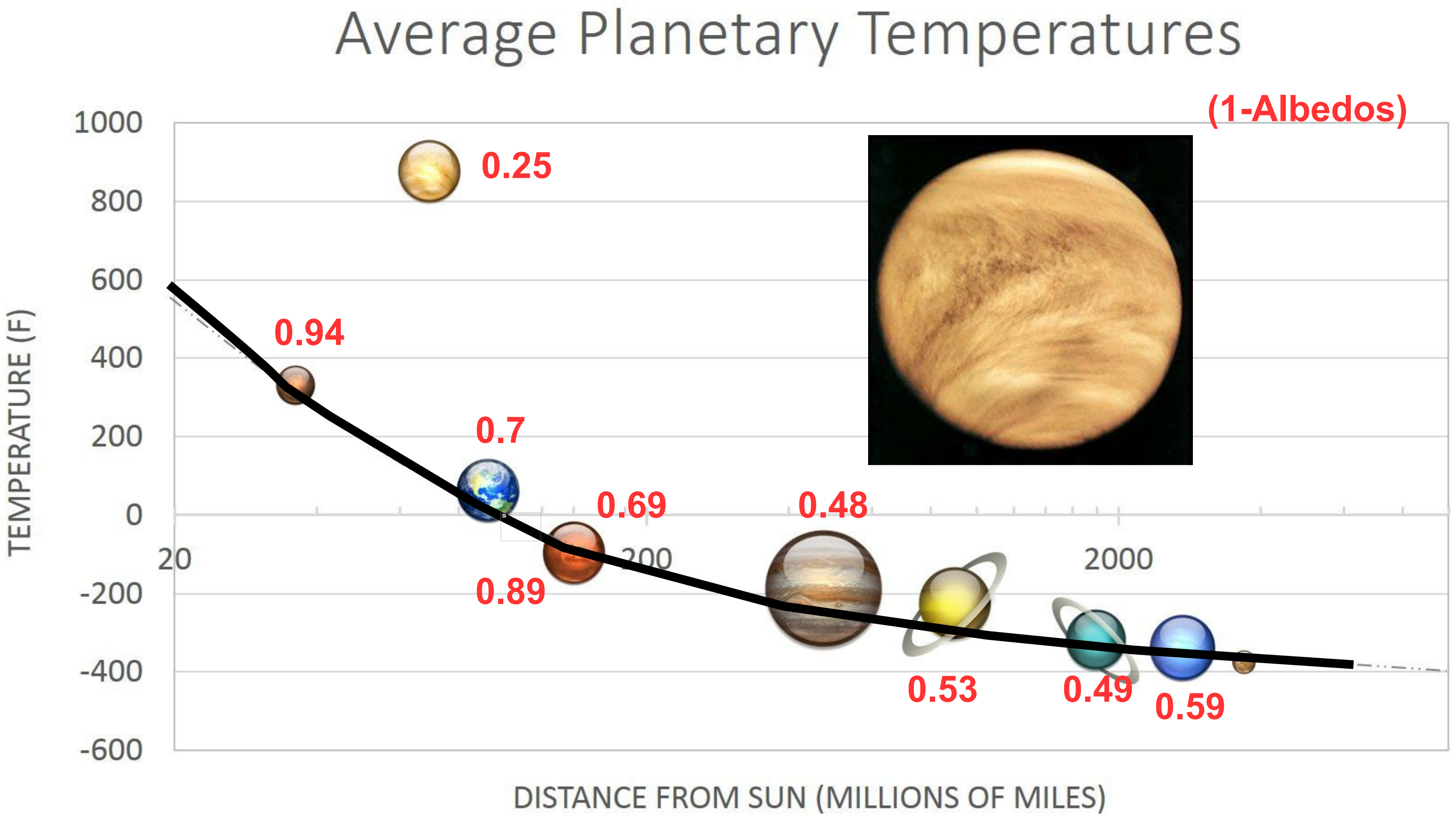
B) Larger

C) unchanged

(cf high-gain antenna)

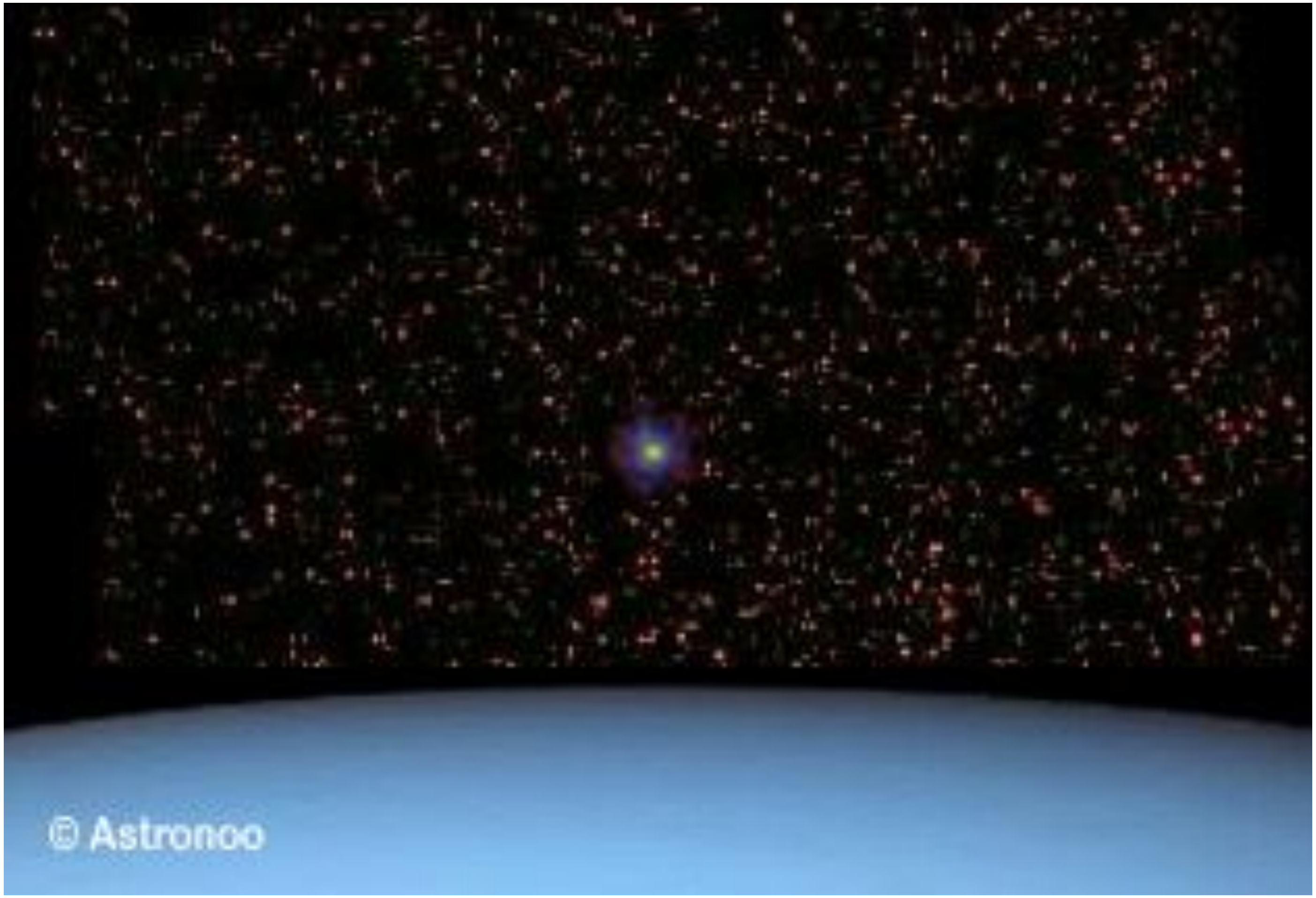
Planet Temperatures: a) distance to sun, b) “albedo”, c) greenhouse effect

http://www.climatefiles.com/climate-change-evidence/presidents-report-atmospher-carbon-dioxide/



- Without CO_2 + CH_4 + N_2O warming, Earth surface temperature would be ~0 F / -18 C (giss.nasa.gov)

View of sun from Uranus



In the previous problem, the total electromagnetic energy delivered to a 50 cm x 50 cm antenna as the echo is measured is closest to:

A) 2.44 J

B) 3.3×10^{-19} J

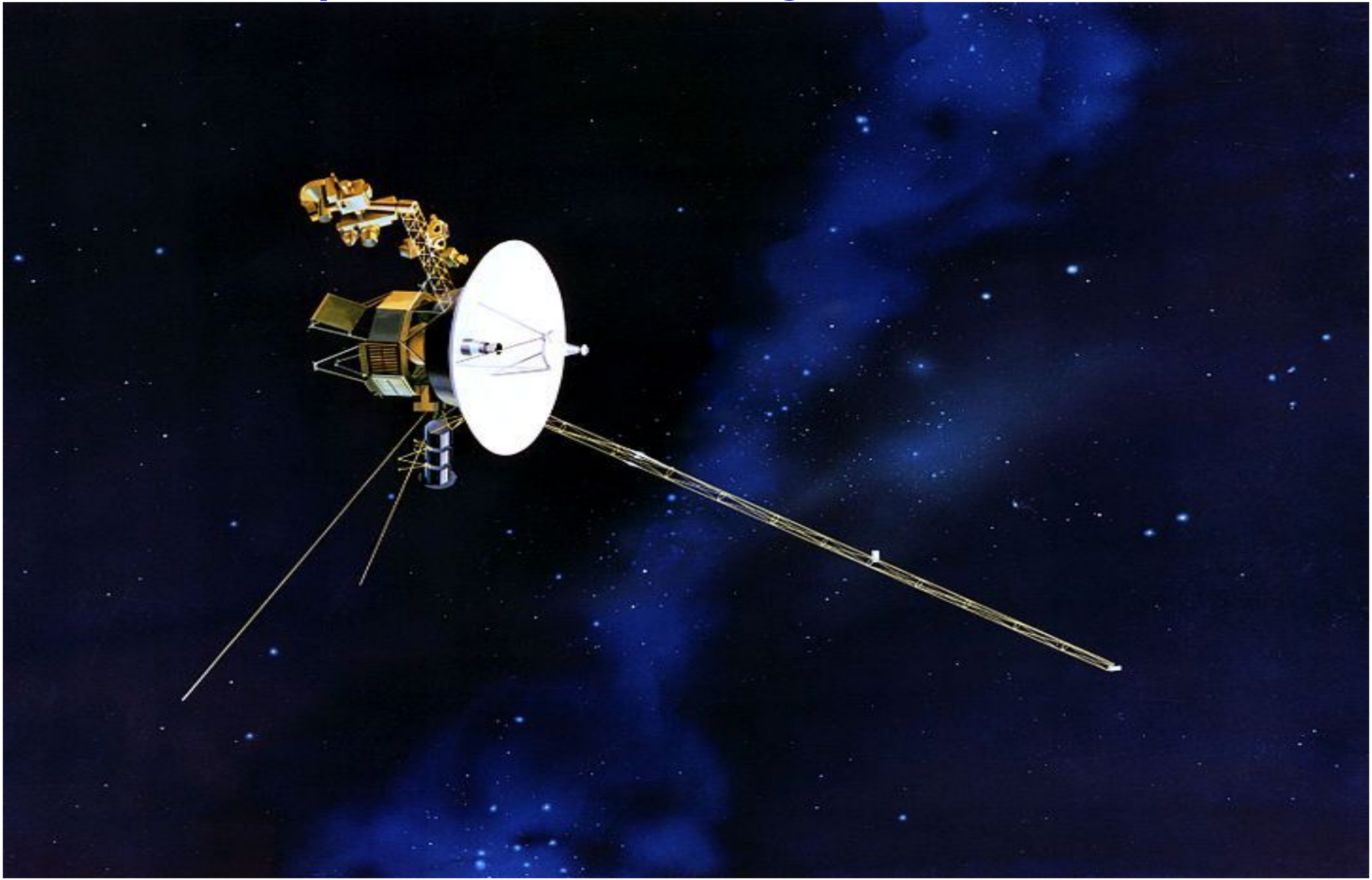
C) 3.3×10^{-11} J

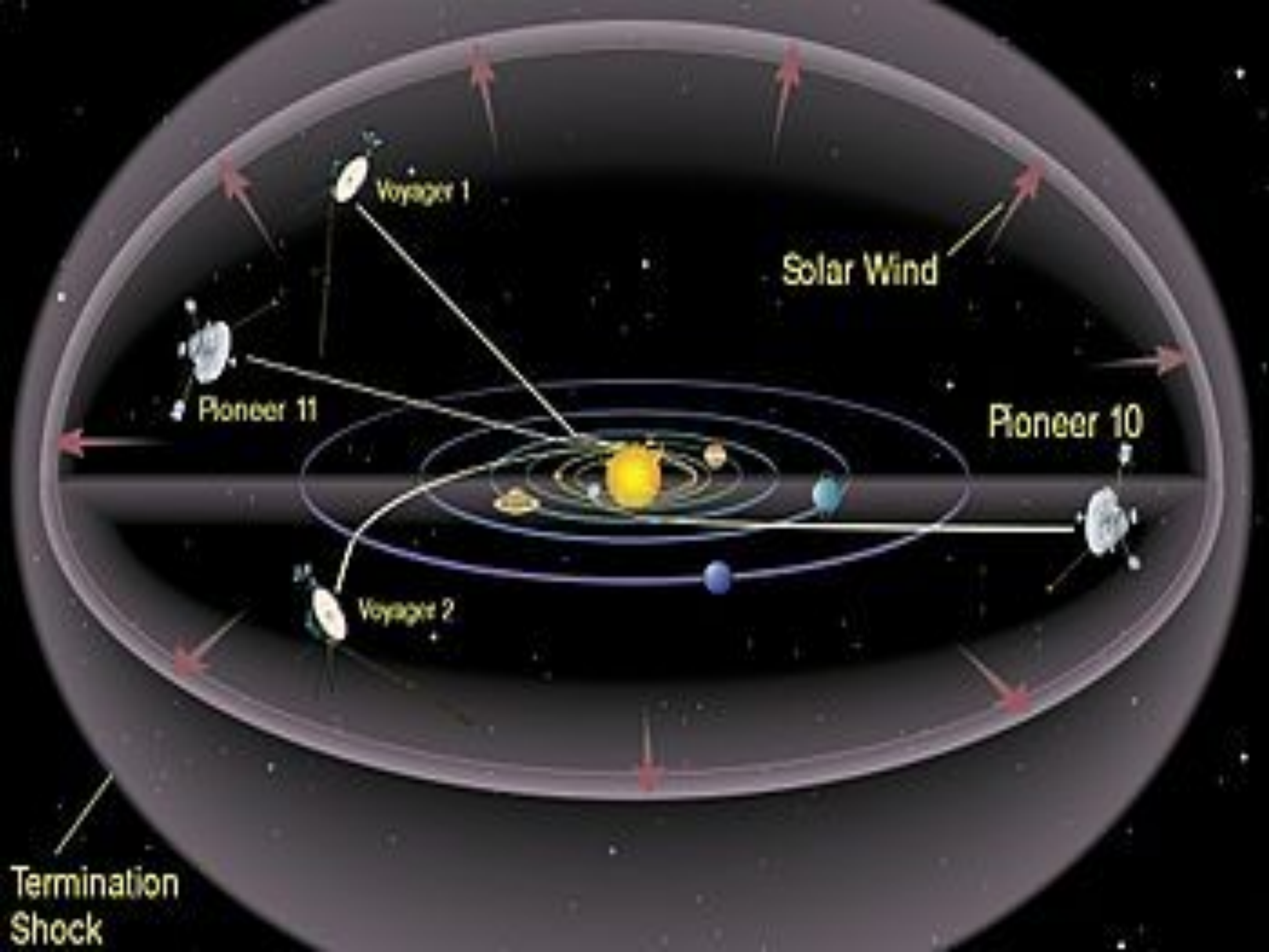
D) 98.33 mJ

By finding the fraction f of total emitted power intercepted, the maximum power output at the source is approximately (assume spherical spreading)

A) 2.44 W
B) 5.2×10^{-2} W
C) 5.2×10^{-10} W
D) 98.33 mW
E) NOTA

Voyager 1, launched on 9/5/77, communicates with Earth from a distance of 133 A.U. (20 x 10^9 km) at a frequency of 2.1-2.3 GHz




Voyager 1
Solar Wind
Pioneer 11
Pioneer 10
Voyager 2
Termination
Shock

The Voyager spacecraft is currently 20 billion km from Earth How long does it take signals to reach the Earth from its current location?

A) About 2 seconds

B) About 9 minutes

C) Almost one day

D) One year

Voyager communicates via 9V solar panel "battery" that charges up a 4F capacitor, which discharges (via relay) in 0.01 ms across a 1 meter long "antenna"; What is the E_{rad} intensity 20 x 10^{10} m away?

A) 17 x 10^{-9} W

B) 17 mW

C) 0.17 mW

D) 10^{-15} Watts

E) NOTA

KANU-FM broadcasts 100 kW at 91.5 MHz. Assuming the power is broadcast spherically, the amount of energy intercepted by a 100-m distant antenna with 2 m^2 coverage, over 4 seconds is:

A) 1 J

B) 6.36 J

C) 12.72 J

D) NOTA

The ANITA experiment measures 10 pW of radio energy over 10^{-7} s. If the balloon is 38 km above the ice surface, the CR interacts 3 km above the surface, and the reflection point is 50 km away, what is the distance to the CR interaction?

The total energy of the CR (assuming spherical spreading) is:

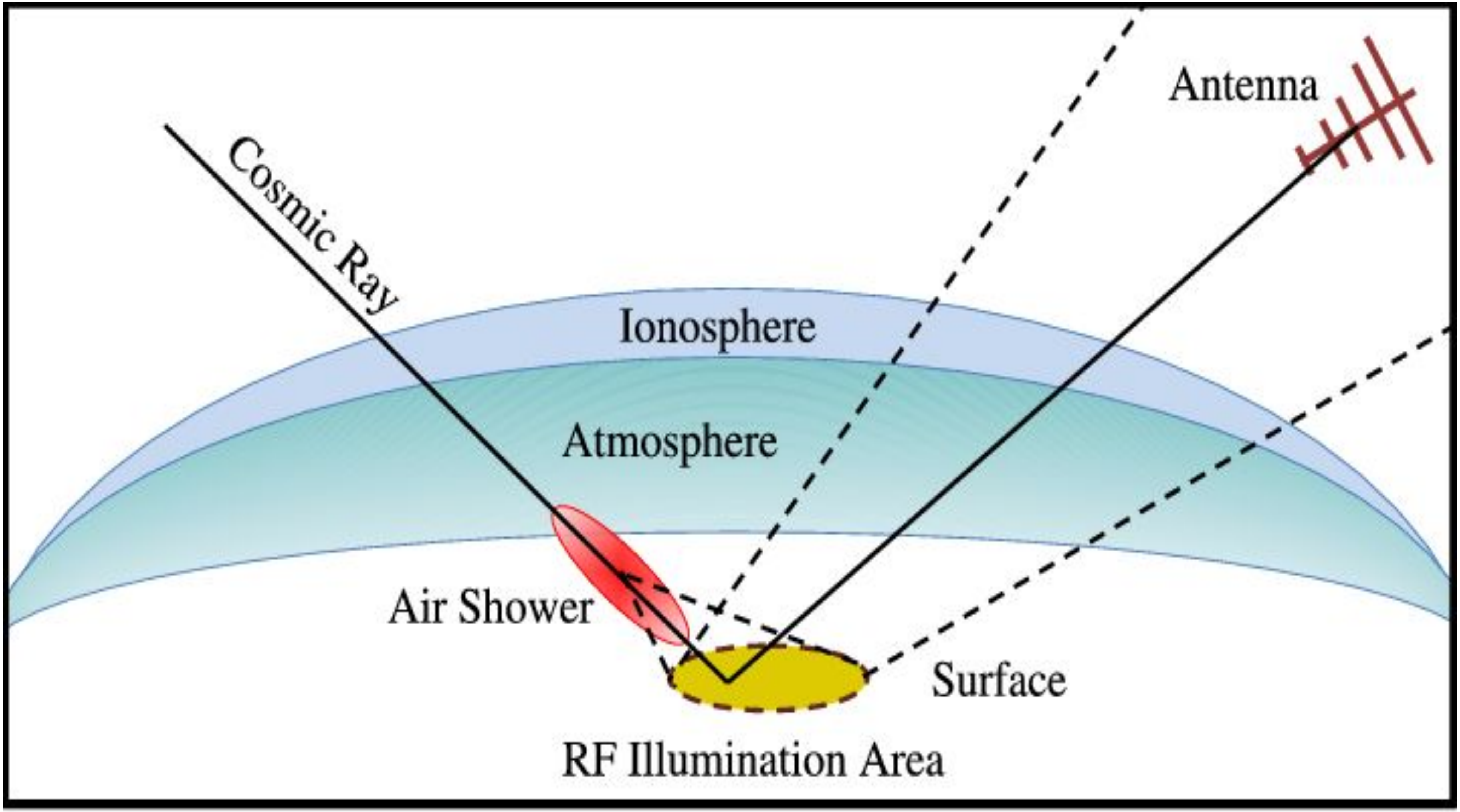
If the power is not beamed into the ground, the previous value

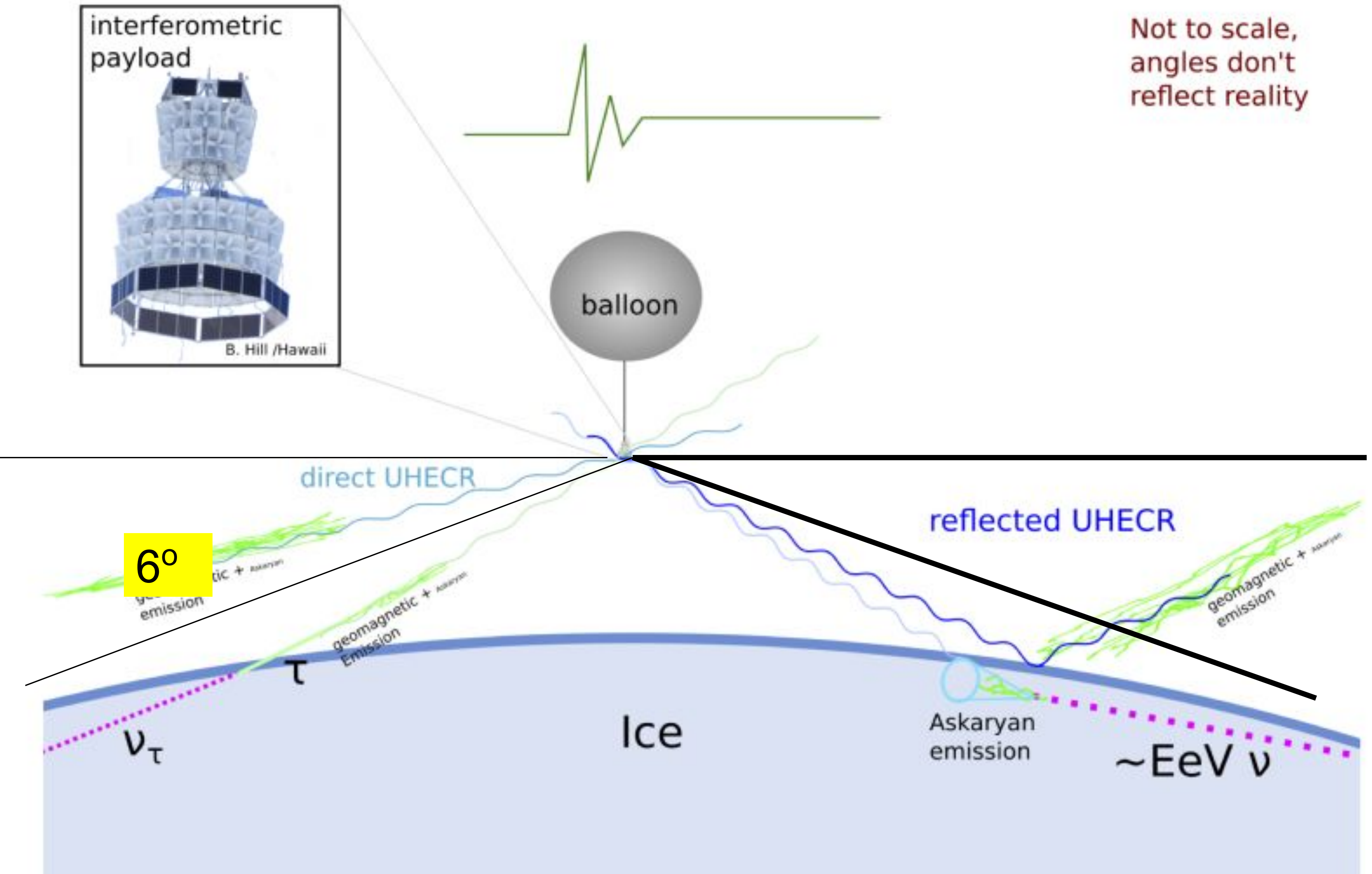
A) Increases

B) Decreases

C) Is unchanged

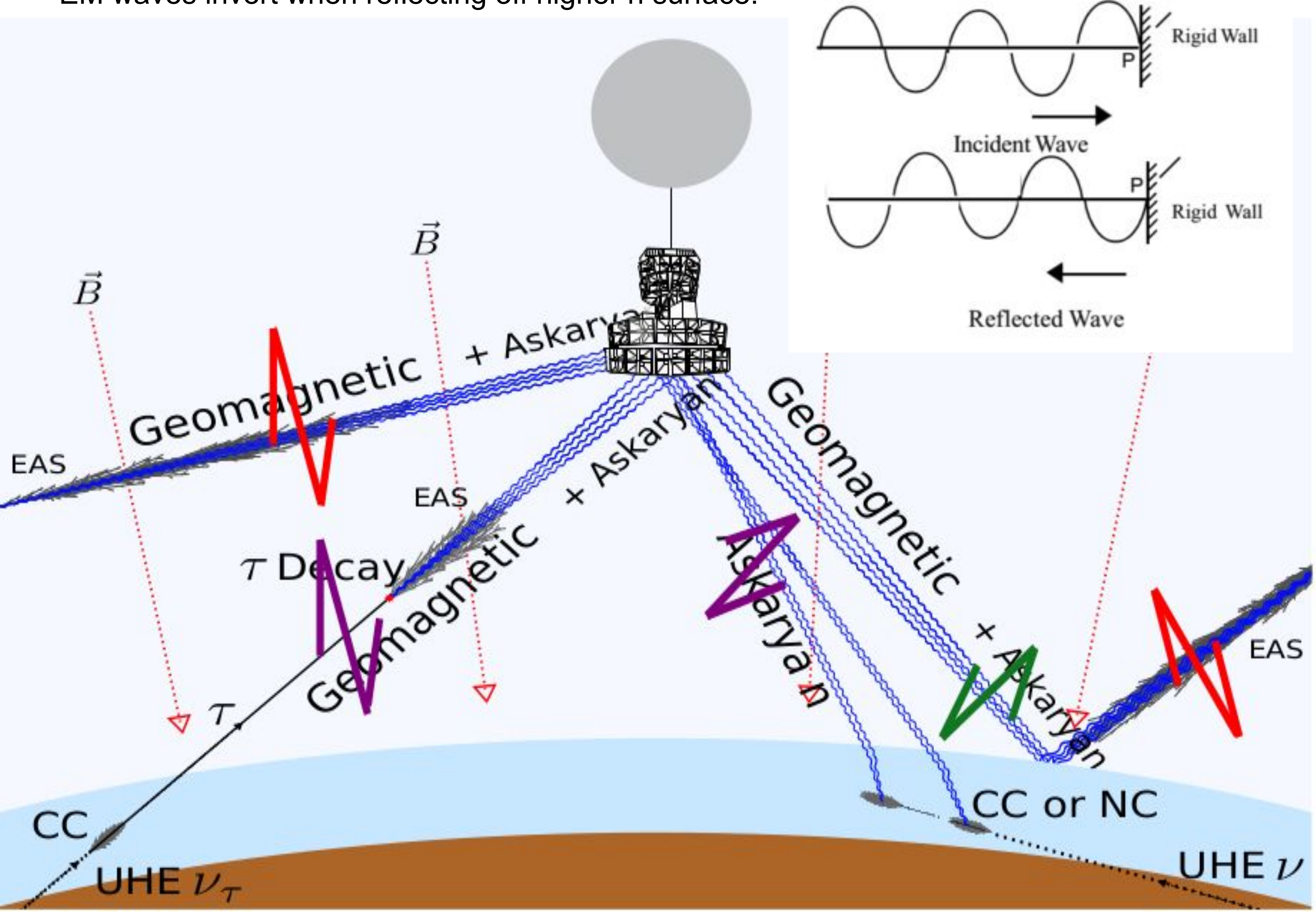
Propagation of electromagnetic radiation, examples (radio-frequency)

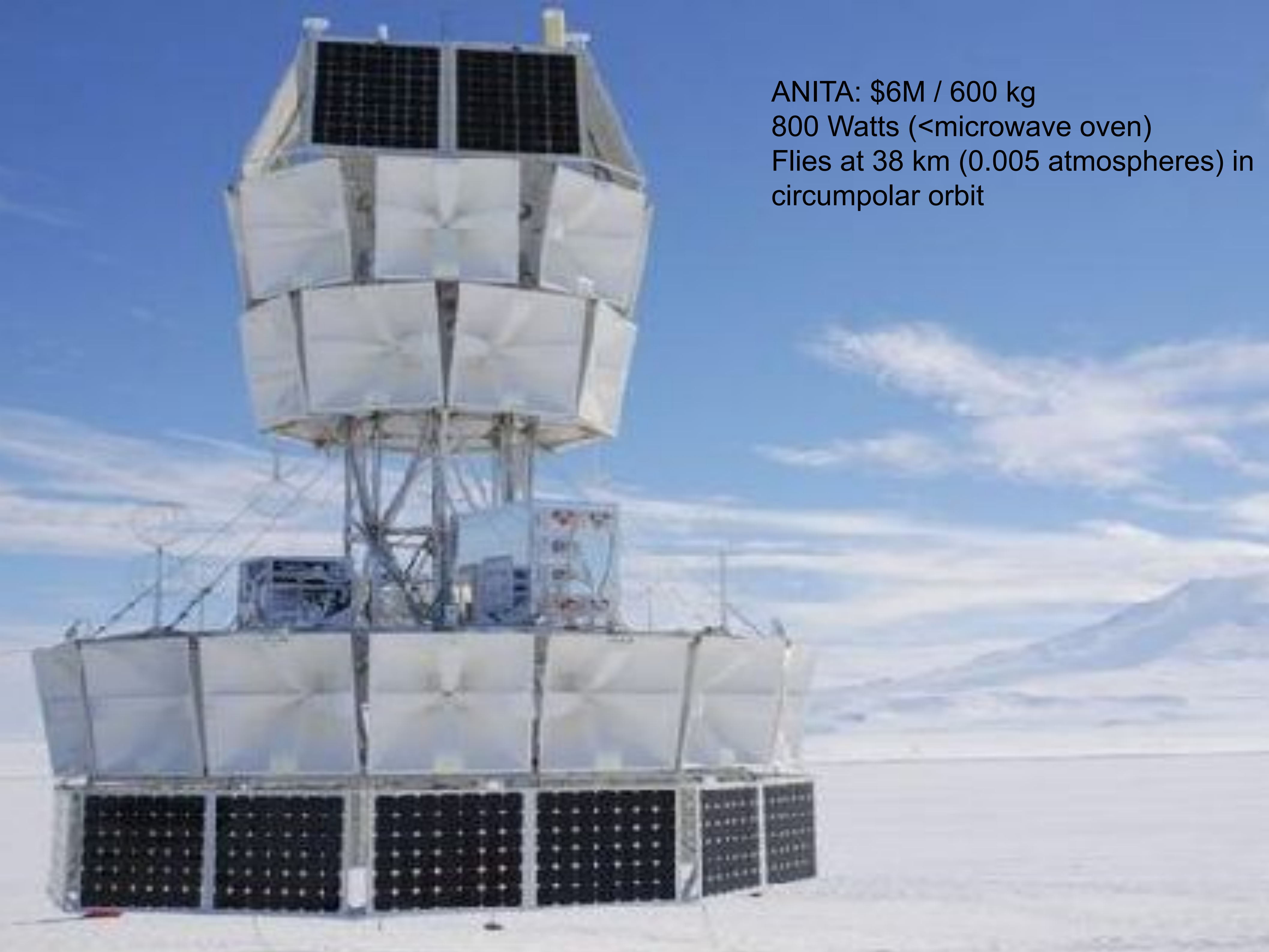

Antenna
Cosmic Ray
Ionosphere
Atmosphere
Air Shower
Surface
RF Illumination Area



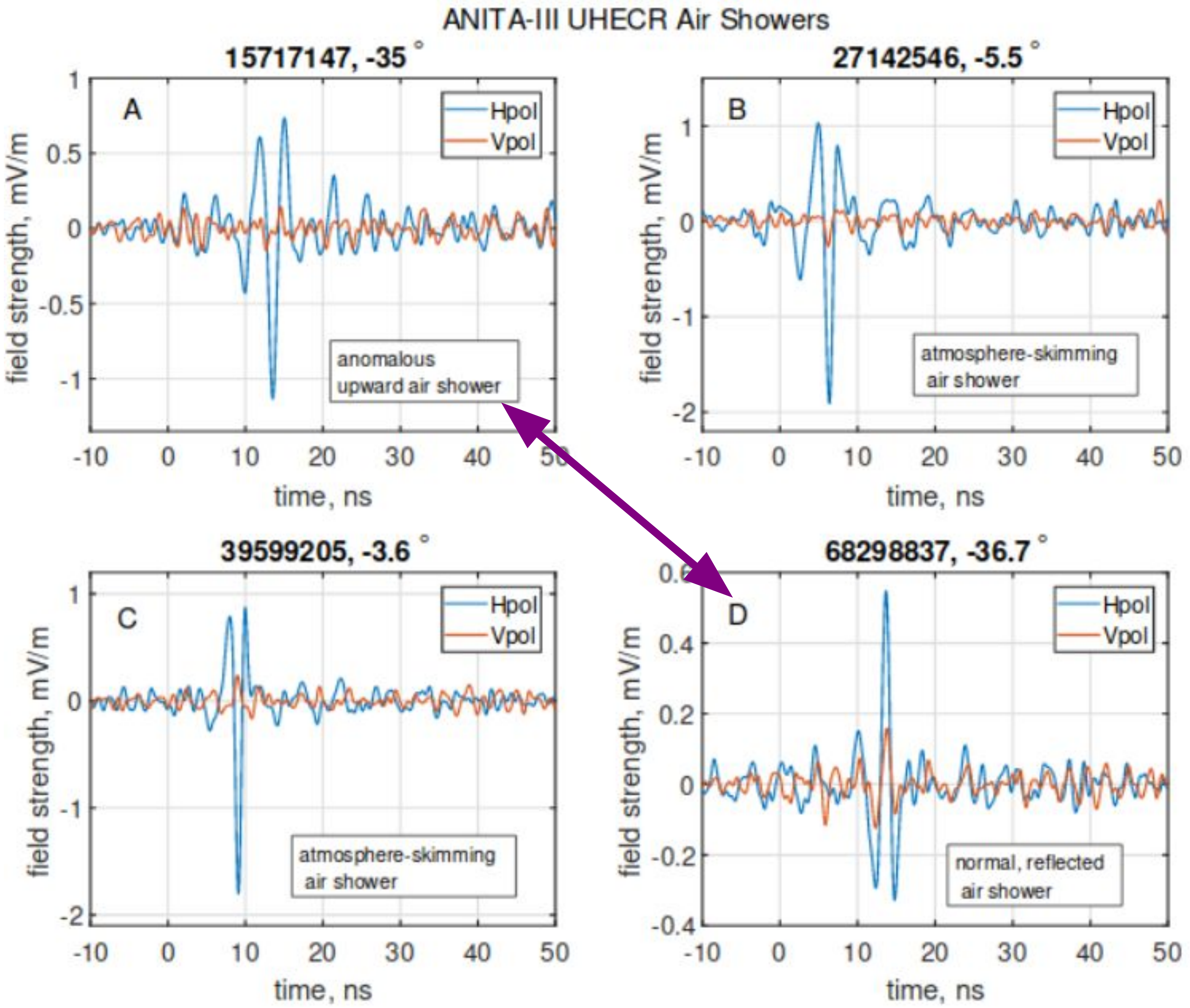
interferometric payload
B. Hill /Hawaii
Not to scale, angles don't reflect reality
balloon
direct UHECR
reflected UHECR
6^o
emission
geomagnetic + Askaryan Emission
geomagnetic + Askaryan emission
τ
ν_τ
Ice
Askaryan emission
~EeV ν

EM waves invert when reflecting off higher n surface!





ANITA: $6M / 600 kg
800 Watts (<microwave oven)
Flies at 38 km (0.005 atmospheres) in circumpolar orbit



ANITA-III UHECR Air Showers
15717147, -35 °
A
Hpol
Vpol
anomalous upward air shower
field strength, mV/m
time, ns
27142546, -5.5 °
B
Hpol
Vpol
atmosphere-skimming air shower
field strength, mV/m
time, ns
39599205, -3.6 °
C
Hpol
Vpol
atmosphere-skimming air shower
field strength, mV/m
time, ns
68298837, -36.7 °
D
Hpol
Vpol
normal, reflected air shower
field strength, mV/m
time, ns

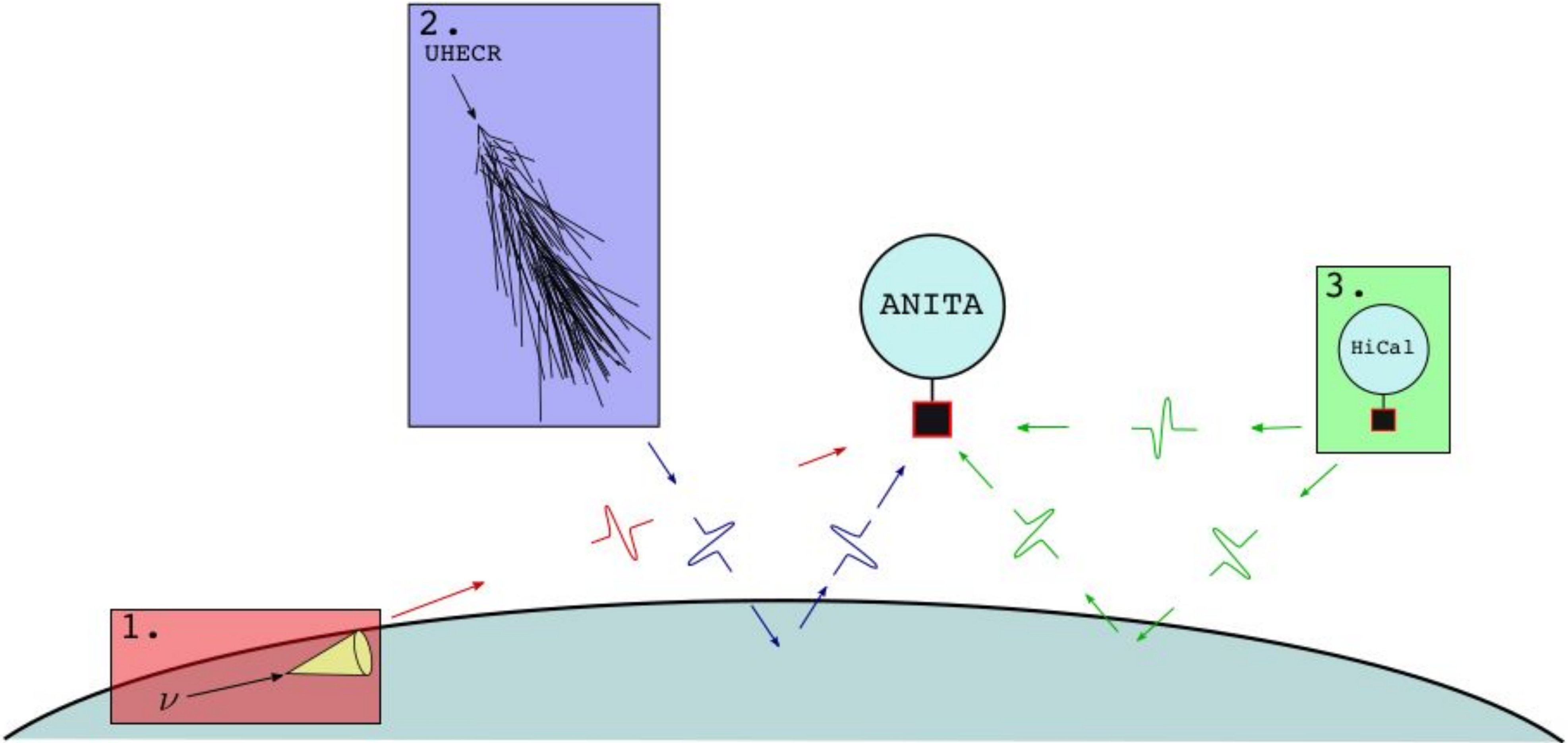
We may have spotted a parallel universe going backwards in time

Strange particles observed by an experiment in Antarctica could be evidence of an alternative reality where everything is upside down

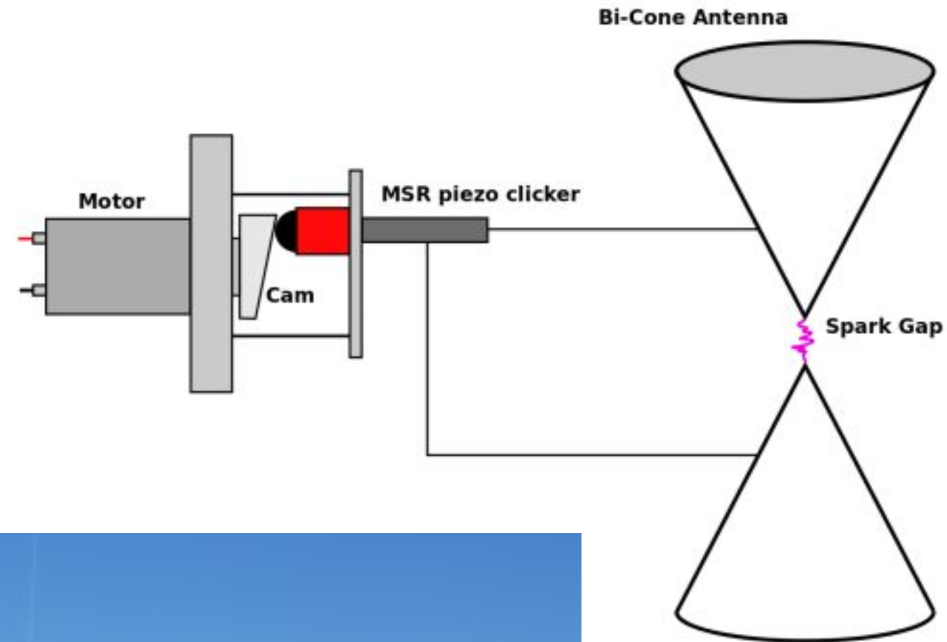
SPACE 8 April 2020

By Jon Cartwright

The HiCal concept: test whether signals really invert if $n_2 > n_1$




MSR
8.3 cm


Bi-Cone Antenna
Motor
MSR piezo clicker
Cam
Spark Gap

voltage, mV

normalzed covariance

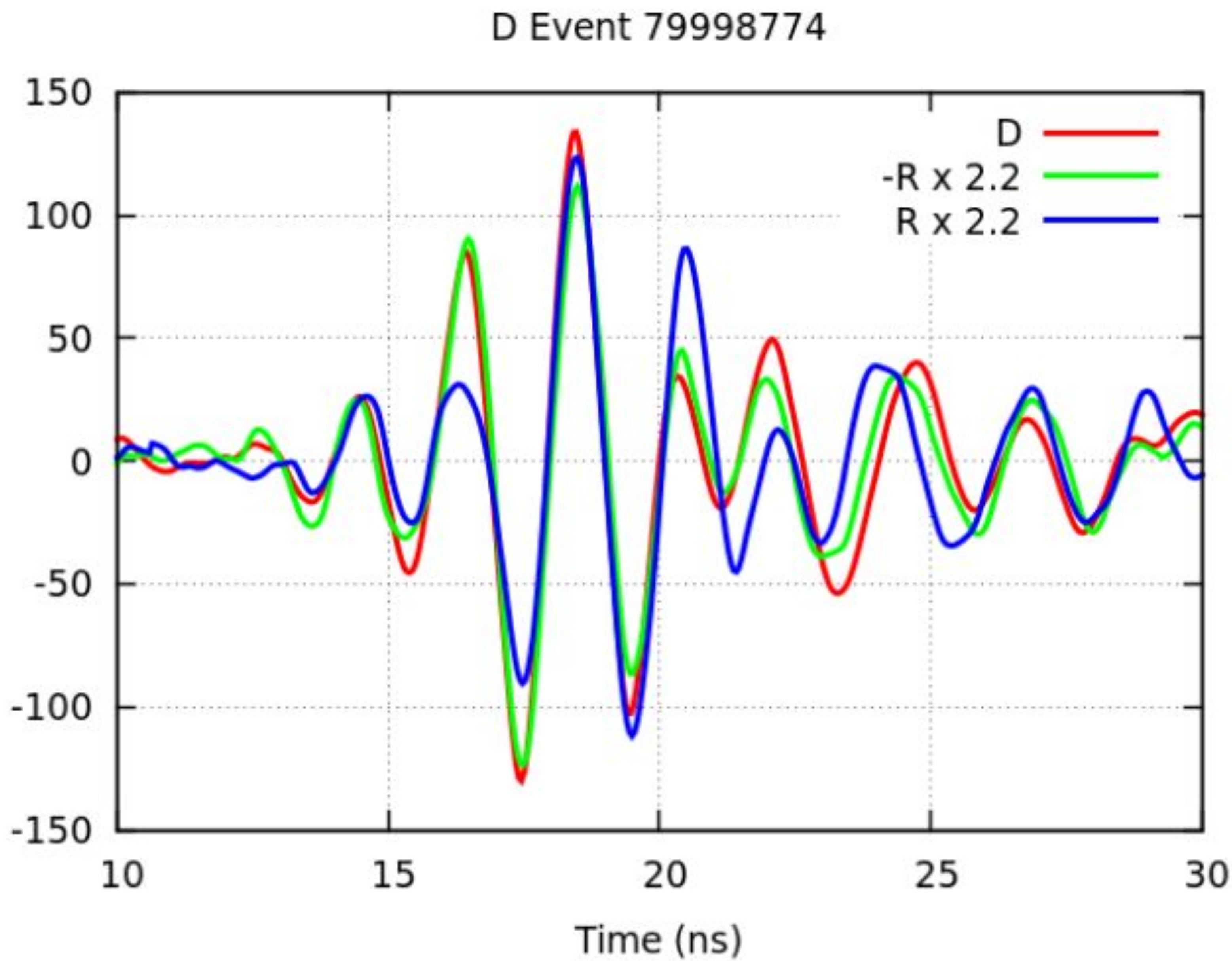
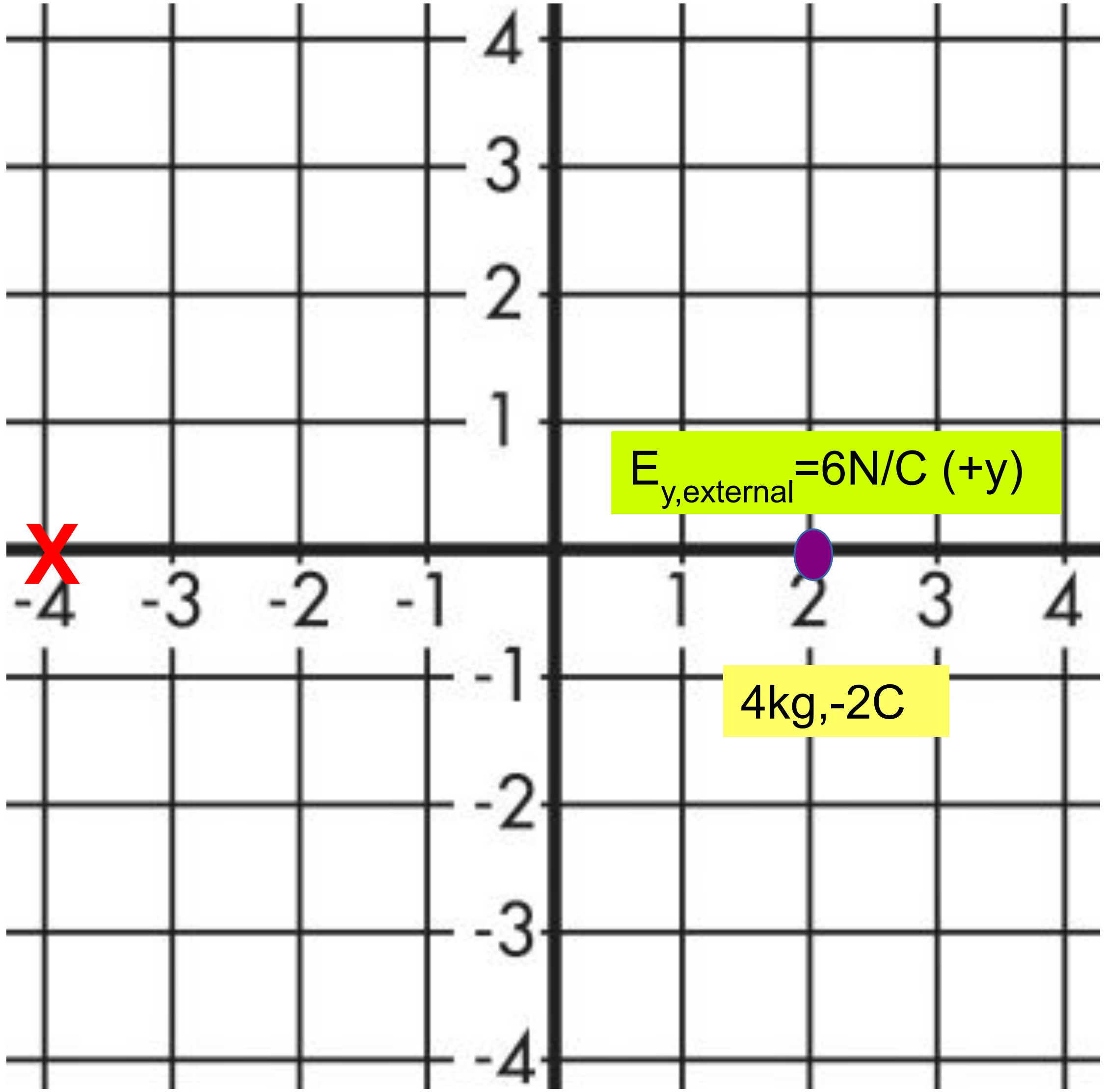


FIG.
deep
the tr
wave
pulse
122 r
reflec

FIG. 10: *Overlay of HiCal-1 Direct event 79998774 (red) overlaid with inverted event 79998775 (green) and non-*

a=F/m=12N/4kg = 3m/s^2 (-y); t to travel 4 m from $y_f=y_i+v_{i,y}t+ ½at^2$ (ignore gravity), so t=1.64 s;



Wave Optics and interference: $v=c/n$; $A(x,t)=A\cos(kx-\omega t+\varphi_0)$; argument describes constant phase condition for $x=ct$; $A(x,t)$ gives amplitude at some given value of x and t.

Interference, including thin film interference, assuming two waves traveling with same velocity

1) Count total number of inversions

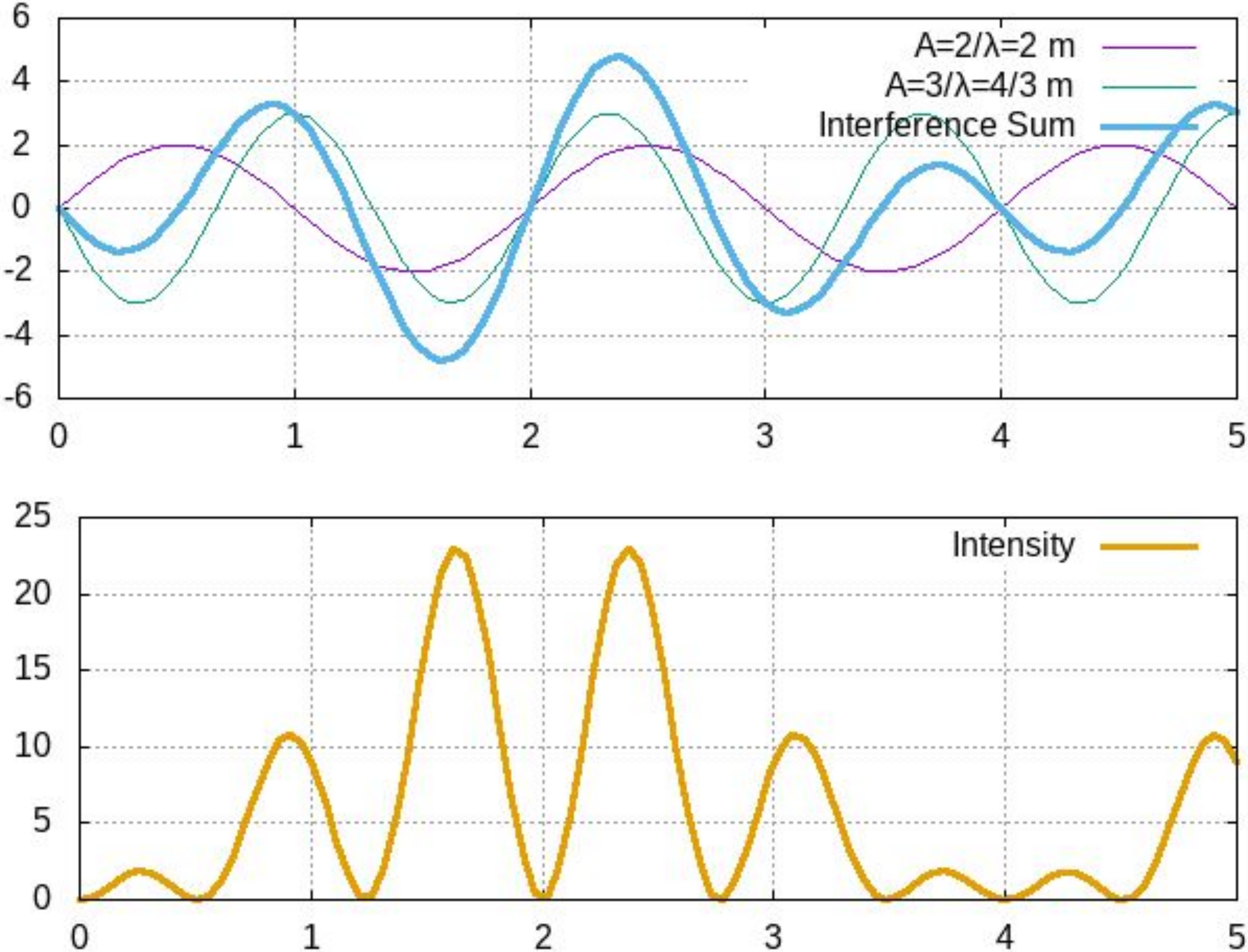
2) If number=even=> minimum thickness from

$$2t=\lambda_{medium}$$

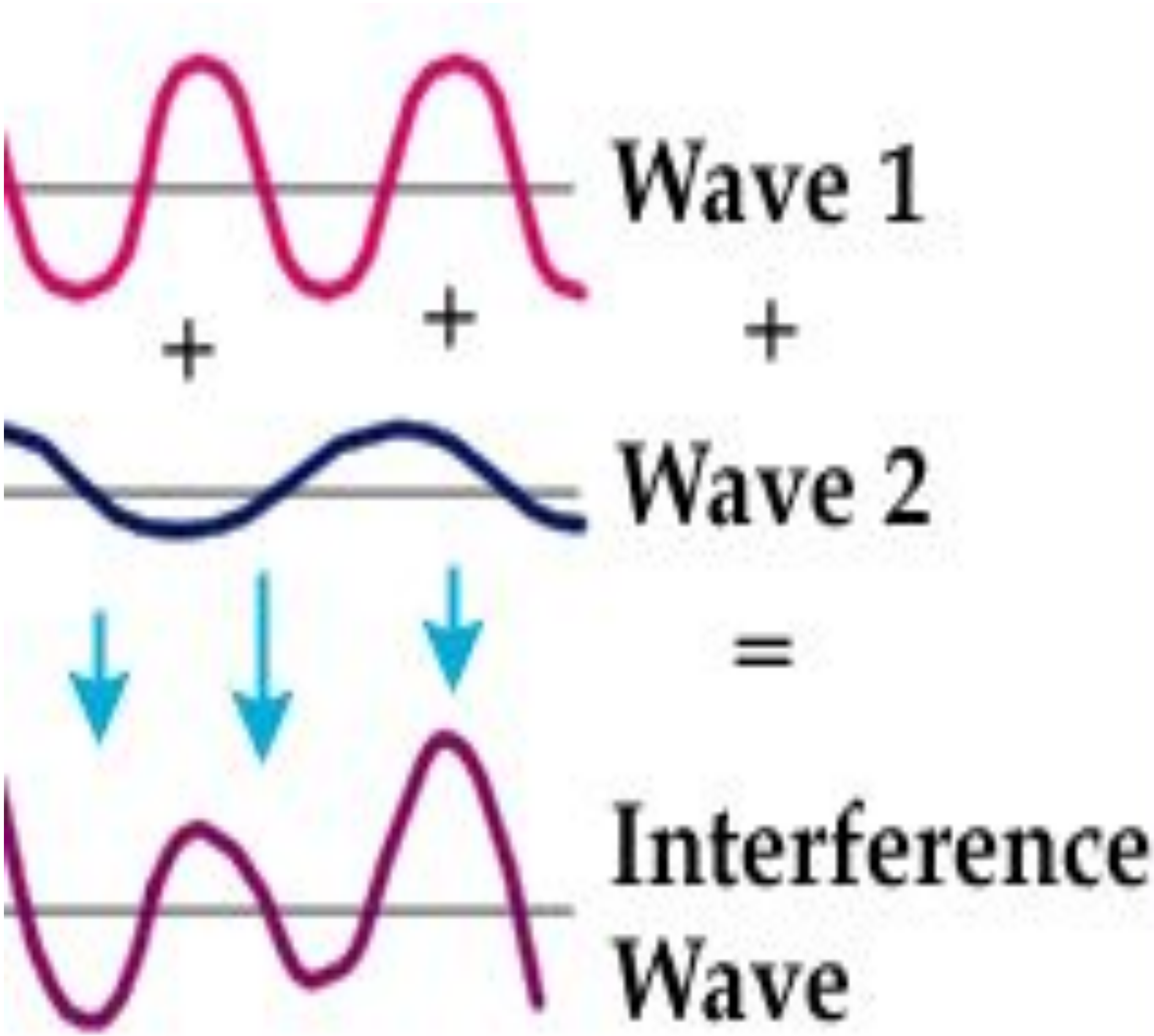
If number odd=>minimum thickness given by

$$2t=\lambda_{medium}/2$$

Next higher thickness: add 1 unit



A=2/λ=2 m
A=3/λ=4/3 m
Interference Sum
Intensity



The interference of water waves coming from two sources.

What is the correct ordering (most negative to most positive) of the net electric field at the points shown?

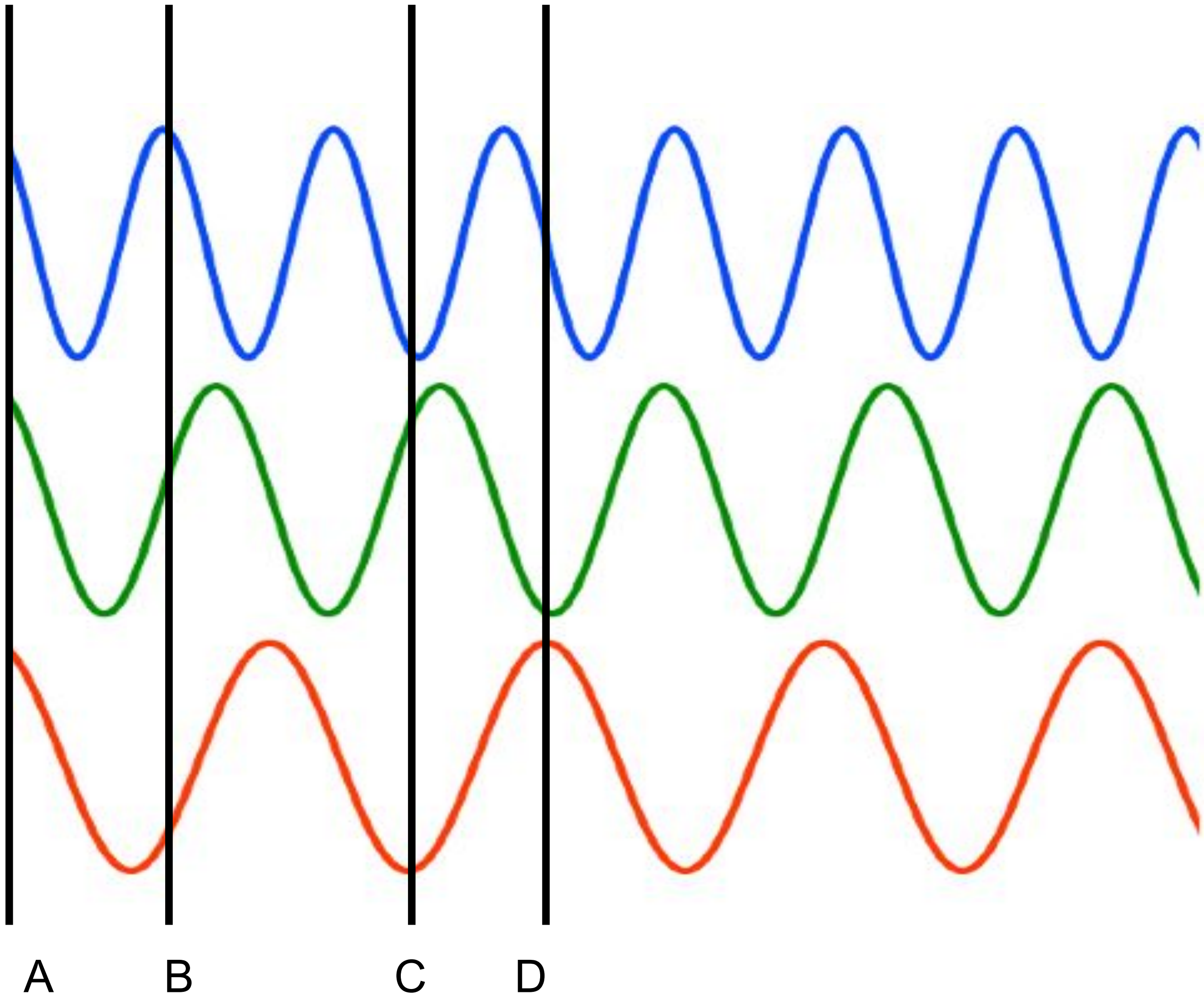
A) A,B,C,D

B) B,C,A,D

C) C,D,B,A

D) D,B,C,A

E) NOTA



What is the correct ordering (smallest to highest) of the net intensity?

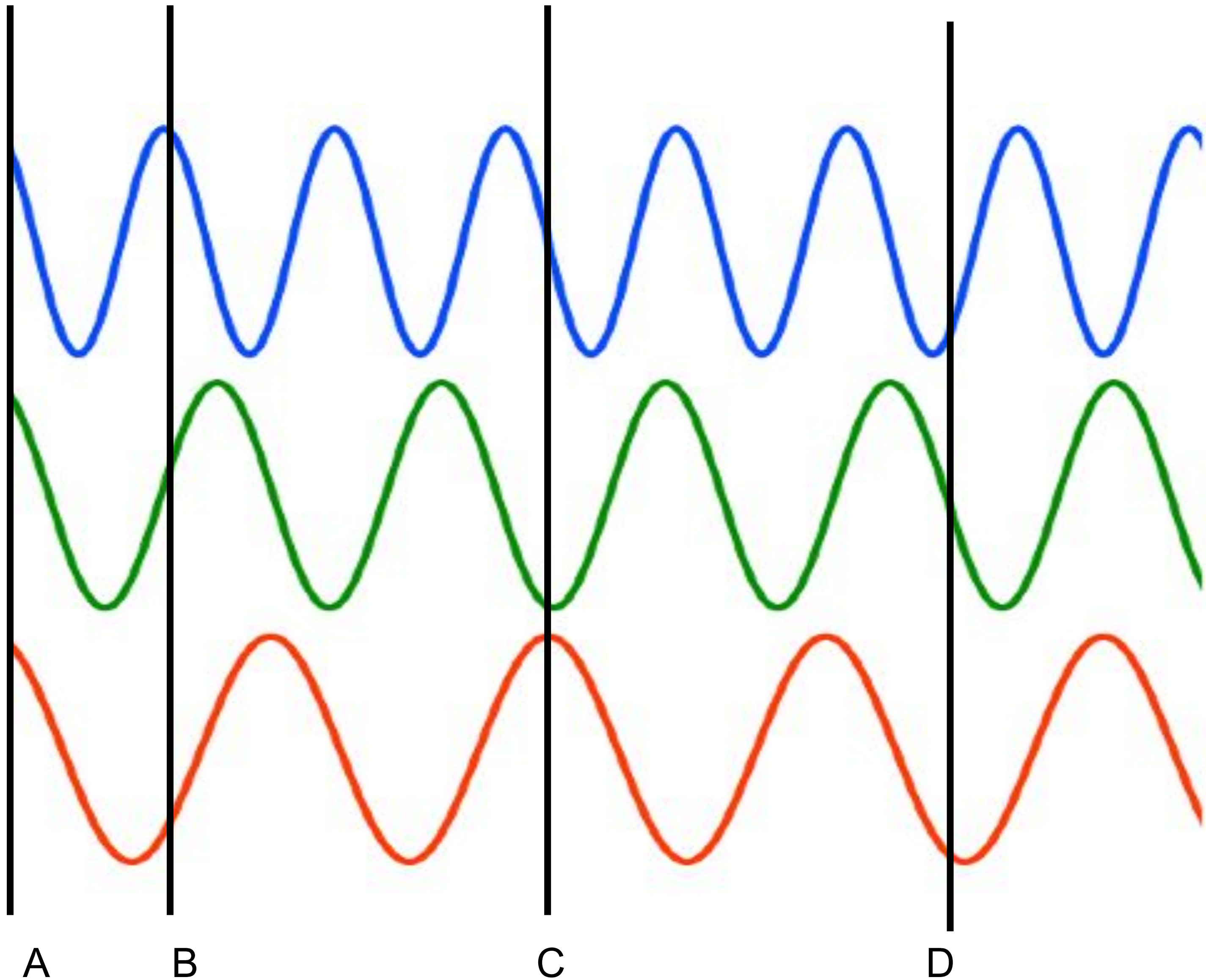
A) A,B,C,D

B) B,C,A,D

C) C,D,B,A

D) D,B,C,A

E) NOTA



Electrons a) and b) are accelerating/oscillating in +/-y at a) 600 MHz b) 150 MHz, with the same amplitude, in two antennas, exactly OUT of phase and sending electromagnetic waves into space. At t_0, electron 1 is at a crest. Given $n_{waves}=d/\lambda$, the ratio of the EM intensity of the two waves, interfering at x=8 m, compared to the EM intensity of just one wave, is closest to:

A) 0

B) 1

C) 2

D) 4

Electrons a) and b) are accelerating/oscillating in +/-y at a) 600 MHz b) 150 MHz, with the same amplitude, in two antennas, exactly OUT of phase and sending electromagnetic waves into air. At t_0, electron 1 is at a crest. The ratio of the EM intensity of the two waves, interfering at x=7 m, compared to the EM intensity of just one wave, is:

A) 0

B) 1

C) 2

D) 4

Two identical charges oscillate in phase, along y, at the origin, and the intensity measured at a point P along the x-axis. Now the second is rotated to oscillate along z, and the maximum intensity re-measured. What is the ratio:

$I_{\text{both y}}:I_{\text{one y, one z}}:I_{\text{one only}}$?

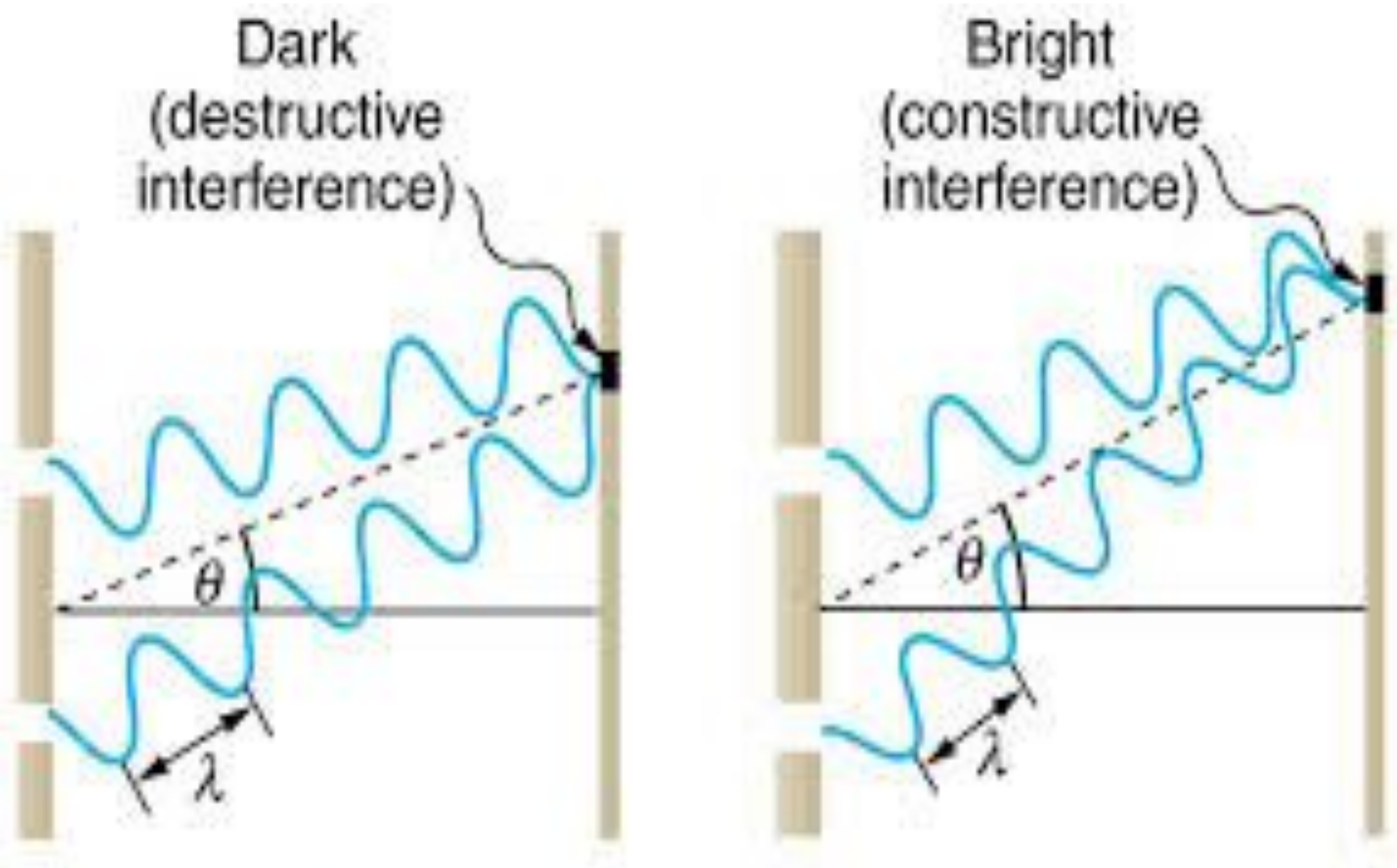
A) 4:2:1

B) 1:1:1

C) 1:2:1

D) 4:1:1

Double Slit interference



(a)
(b)

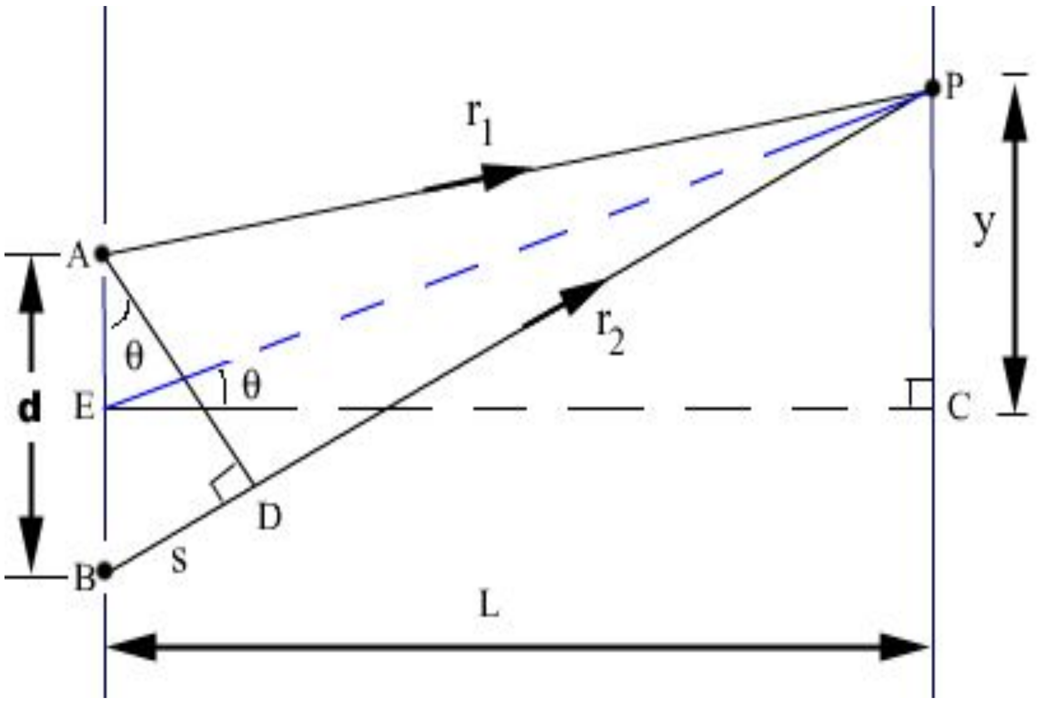
In the diagram below, which formula corresponds to the angles θ at which bright spots are observed?

A) A) $m\lambda = d\sin(\theta/2)$

B) B) $m\lambda = d\sin(\theta)$

C) C) $m\lambda = d\cos(\theta/2)$

D) D) $m\lambda = d\cos(\theta)$



50 MHz radio waves oscillate out of phase, at y=-1 m and y=1 m. The point P at the midpoint of a screen is

A) always bright

B) always dark

C) alternately bright and dark

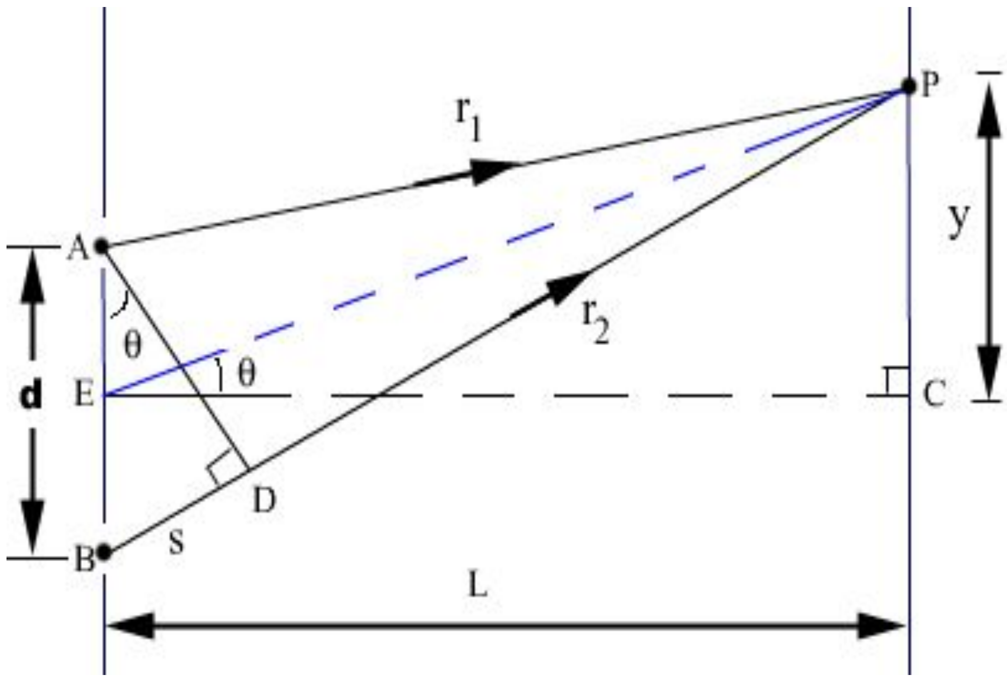
If they are oscillating in-phase, what distances r_1 and r_2 ($=r_1+s$) will give a dark spot at P?

A) r_1=18 m; r_2=24 m

B) r_1=21 m; r_2=27 m

C) r_1=21 m; r_2=24 m

D) NOTA



Two spherical radio sources, emitting in-phase at 600 MHz, are placed 2 m apart. Find the angle (above x-) at which the radio waves first interfere constructively on a distant screen.

A) 14.4^{O}

B) 22.6^{O}

C) 33.9^{O}

D) 44.4^{O}

E) NOTA

If d=1 cm, l=4 mm, L=10 cm, what is z such that there is destructive interference at the distance z?

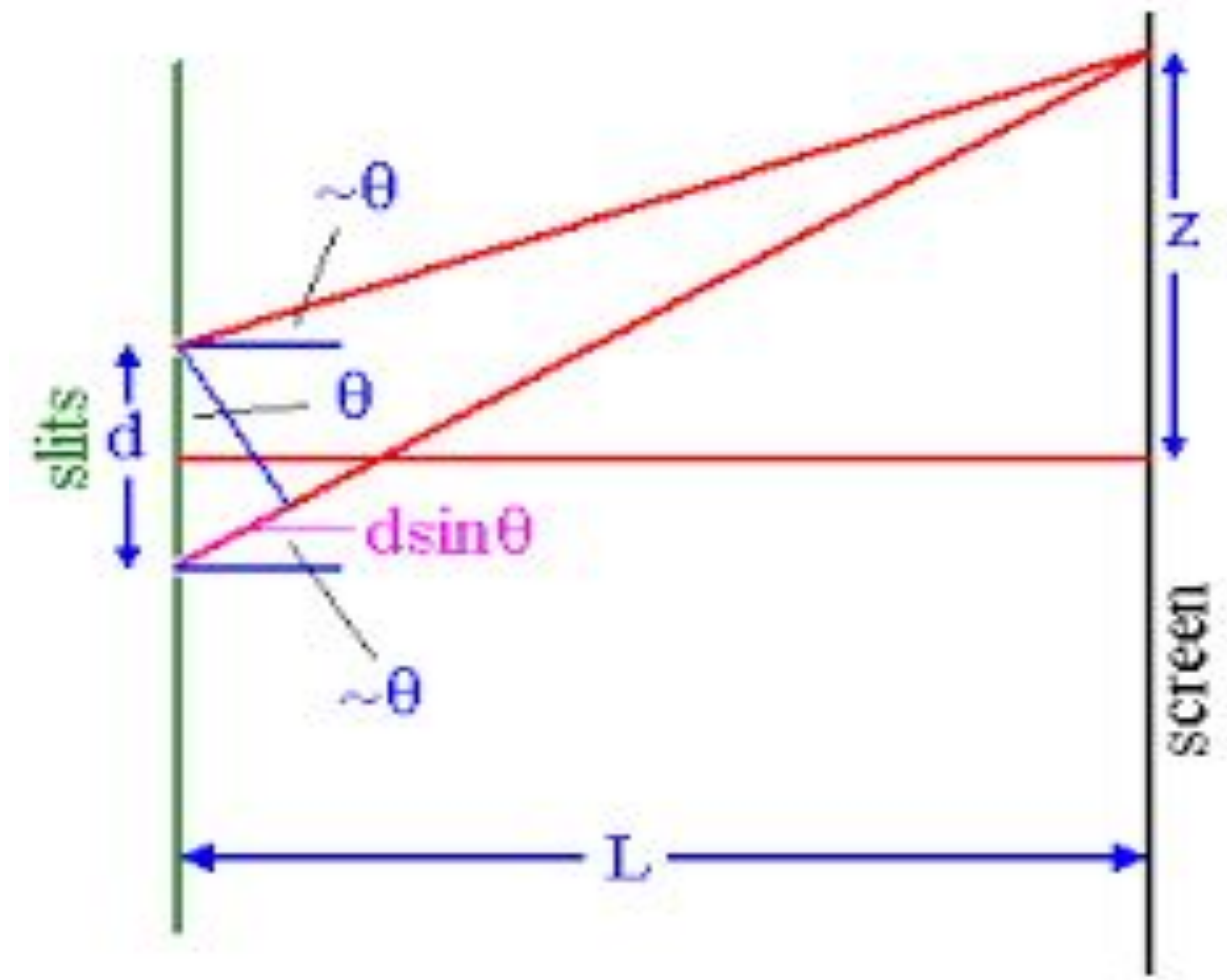
A) 1.32 cm

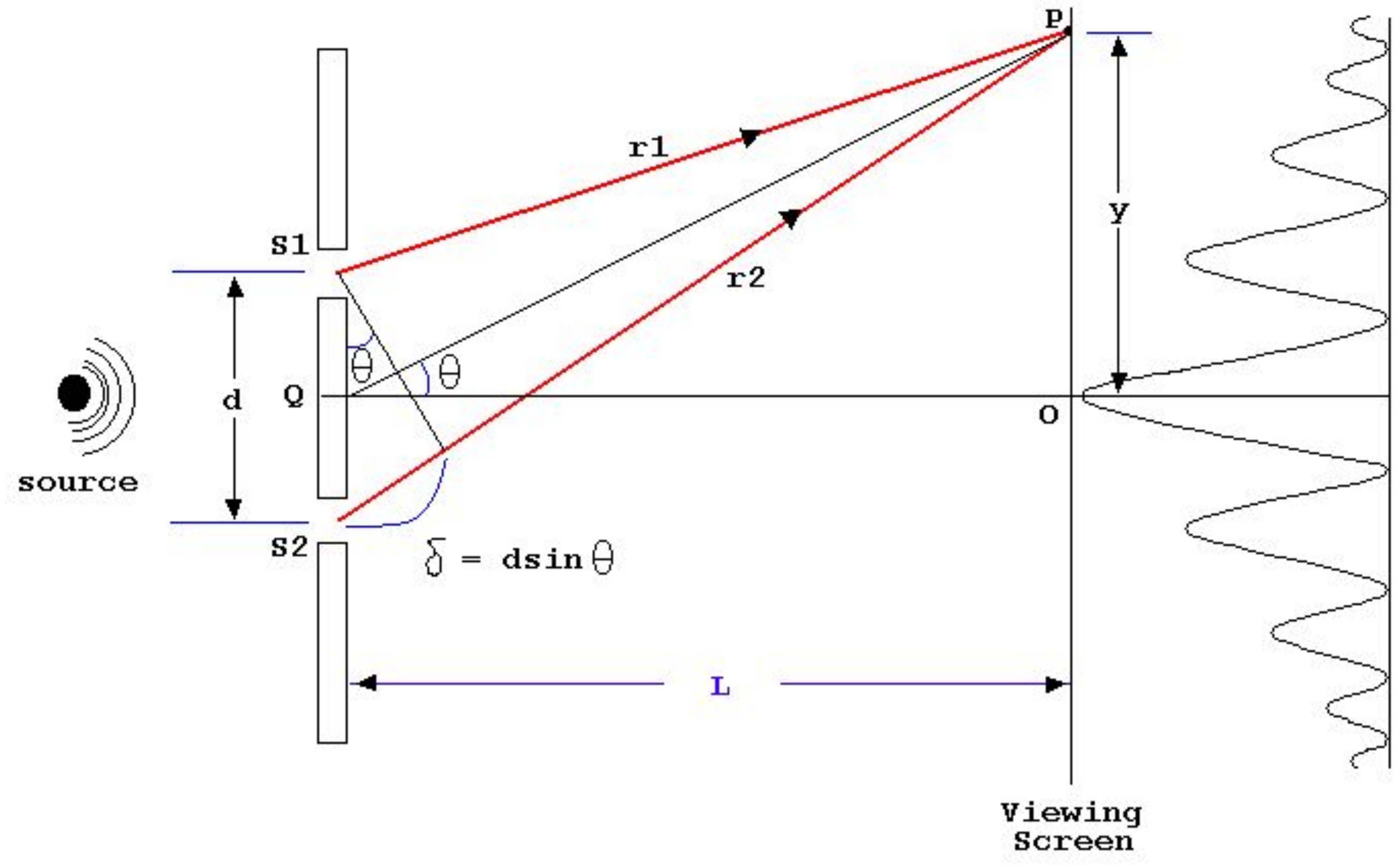
B) 4.36 cm

C) 2.18 cm

D) 3.33 cm

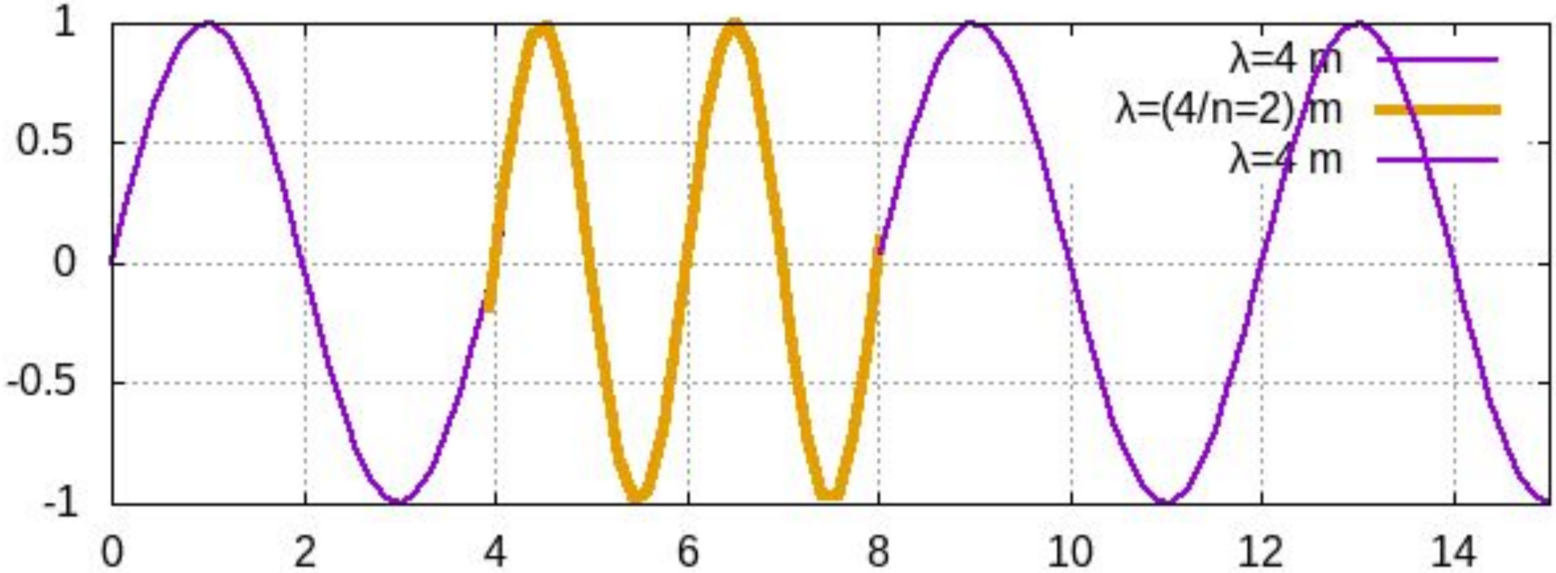
E) NOTA

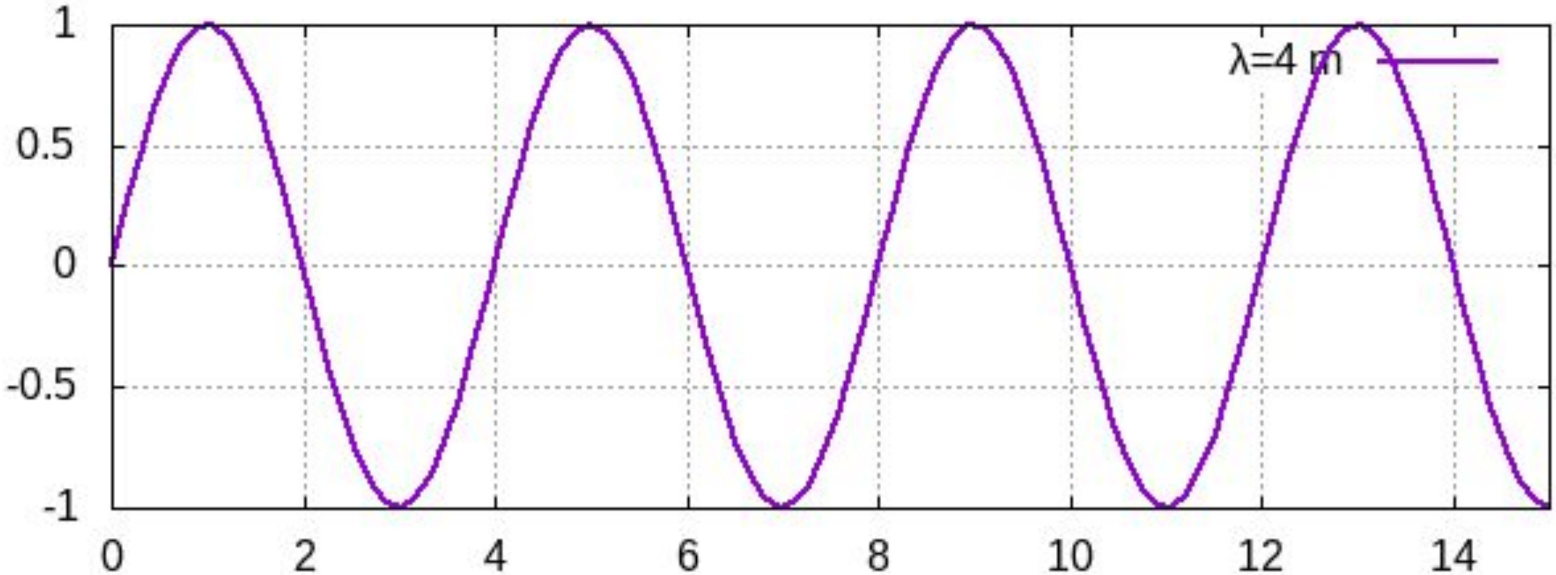




Suppose L=4 m, f=1500 MHz ($\lambda=c/f=20$ cm), d=120 cm.
Angle of 2nd bright spot on screen: $m\lambda=d\sin\theta$, with m=2, so $\theta=\arcsin(2*20cm/120cm)=0.34$ rad, so y=1.41 m
Angle 3rd dark spot on screen: $(m+½)\lambda=d\sin\theta$, with m=2, as well; $\theta=0.43$ rad, so $\tan\theta=y/L$, or y=1.83 m

In this case, waves are in phase at source. We want phase relationship 15 m from source:
Top path: n_{waves}=(4m in x)/(4m λ)+(4 m)/(2m λ)+(7m in x)/(4m λ)=5.75
Bottom path: (15m/4m wavelength)=4.75
Difference=one wavelength, so phase relationship identical to phase at source!





Given the three electric field vectors shown, after passing through polarizers. The ratio of the EM power (A+B+C)/(A+B) is about:

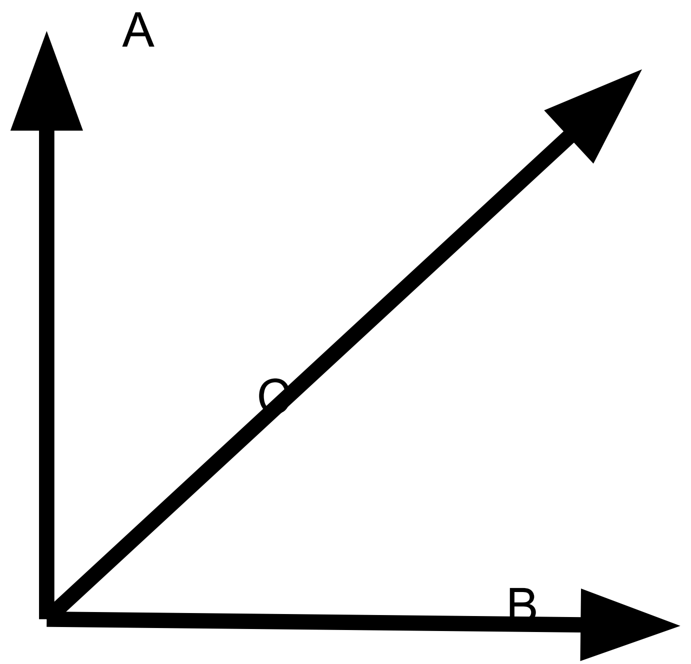
A) 1

B) 2

C) 4

D) 8

E) 16



Vertically polarized light is passed through: a) two successive polarizers at 45°, b) one polarizer at 90°, and c) two successive polarizers at 30°. The relative intensities a:b:c are:

A) ¼:0:9/16

B) ½:0/0.866

C) ½: ¼ : 1/9

D) 1:2:4

E) NOTA

Waves are produced at the origin, which then travel through glass (n=1.667). At x=4 m, Billy Zoom measures $6x10^7$ waves passing per second, with $|E_{rad,max}|$=4 V/m. What is E_{rad} for this wave at x=8 m, t=6 ns (assuming spherical spreading)?

A) 4V/m

B) 2V/m

C) -0.69 V/m

D) -1.38 V/m

E) NOTA

Charge 1 oscillates with a frequency of 1200 MHz at x=-1 m; charge 2 oscillates with a frequency of 150 MHz at x=-3 m. At x=1 m, you measure an $E_{rad,1}$ magnitude (amplitude) of 1 V/m, and an $E_{rad,2}$ magnitude of 2 V/m. At t=3.33 nanoseconds, what is the ratio of the intensity of wave 2 only, relative to the intensity of wave 1 only?

A) 1

B) 2

C) 4

D) 8

E) NOTA

Charge 1 oscillates with a frequency of 1200 MHz at x=-1 m; charge 2 oscillates with a frequency of 150 MHz at x=-3 m. At x=1 m, you measure an $E_{rad,1}$ magnitude (amplitude) of 1 V/m, and an $E_{rad,2}$ magnitude of 2 V/m. At t=3.33 nanoseconds, what is the ratio of the intensity of waves 1+2 together, relative to the intensity of wave 1 only?

A) 1

B) 2

C) 4

D) 8

E) NOTA

In the previous problem, if source 2 were oscillating along z-, the net intensity I_{1+2} would:

A) Increase
B) Decrease
C) Be unchanged

A charge Q at (0,0) oscillates at 50 MHz into a 'waveguide'; at x=1 m, $|E_{max}|$=4 V/m. At x=8 m, O measures E=-4 V. At what time did O make the measurement?

A) 44.9 ms
B) 36.6 ns
C) 1.02 seconds
E) NOTA

Which statement is true?

A) At a slight time later, the measured value of electric field is still negative, but smaller in magnitude.

B) At a slight time later, the measured value of electric field is still negative, but larger in magnitude

C) At a slight time later, the measured value of electric field is now positive.

D) At a slight time later, the measured value of electric field is still negative, but may be either larger or smaller in magnitude.

At t=60 ns, someone measures E=-2V. What is the position at which the measurement is made?

Which statement is true?

A) At a slight time later, the measured value of electric field is still negative, but smaller in magnitude.
B) At a slight time later, the measured value of electric field is still negative, but larger in magnitude
C) At a slight time later, the measured value of electric field is now positive.
D) At a slight time later, the measured value of electric field is still negative, but may be either larger or smaller in magnitude.

If, instead of being channeled into a waveguide, energy is emitted spherically, if $|E_{max}|$ at x=1 is 4V/m, what is $|E_{max}|$ at x=4m?

A) 4V/m

B) 2V/m

C) 1V/m

D) 0.5 V/m

E) NOTA

The peak electric field strength in case 1, relative to case 2 is

A) Smaller by a factor of 2

B) Smaller by a factor of 4

C) Smaller by a factor of sqrt(2)

D) unchanged

A_1=2 m, f=400 MHz; A_2=1 m, f=150 MHz;
out-of-phase at source, x=9 m, so λ_1=0.75 m; λ_2=2 m;
n_1=9/0.75=12 waves; n_2=4.5 waves so A_1=crest, A_2 also at crest, so Atot=3, so I_{tot}=9; verify:
$A_1(x=9)=2*\cos(2\pi*9/0.75+0)=2$ (check!)
$A_2(x=9)=1*\cos(2\pi*9/2+\pi)=1.0$ (check!)

d=1 m; f=3000 MHz; screen 2 m away, so solve for θ:
$0.1=\sin\theta$, so θ=5.74 degrees
so height along screen given by $\tan\theta$=h/2m, so h=20 cm for first interference maximum

1) Accelerating charges => E_{rad} and B_{rad}

2) Oscillating, accelerating Q=>EM waves (radiation)

   A) Characterized by Amplitude A, frequency f, wavelength λ, wavespeed ("c" or "v"): $f\lambda=c$

      A) Also 'phase' (at crest or trough at starting point, e.g.)

   B) "Intensity" ~ A^2

   C) Waves overlapping 'interfere'

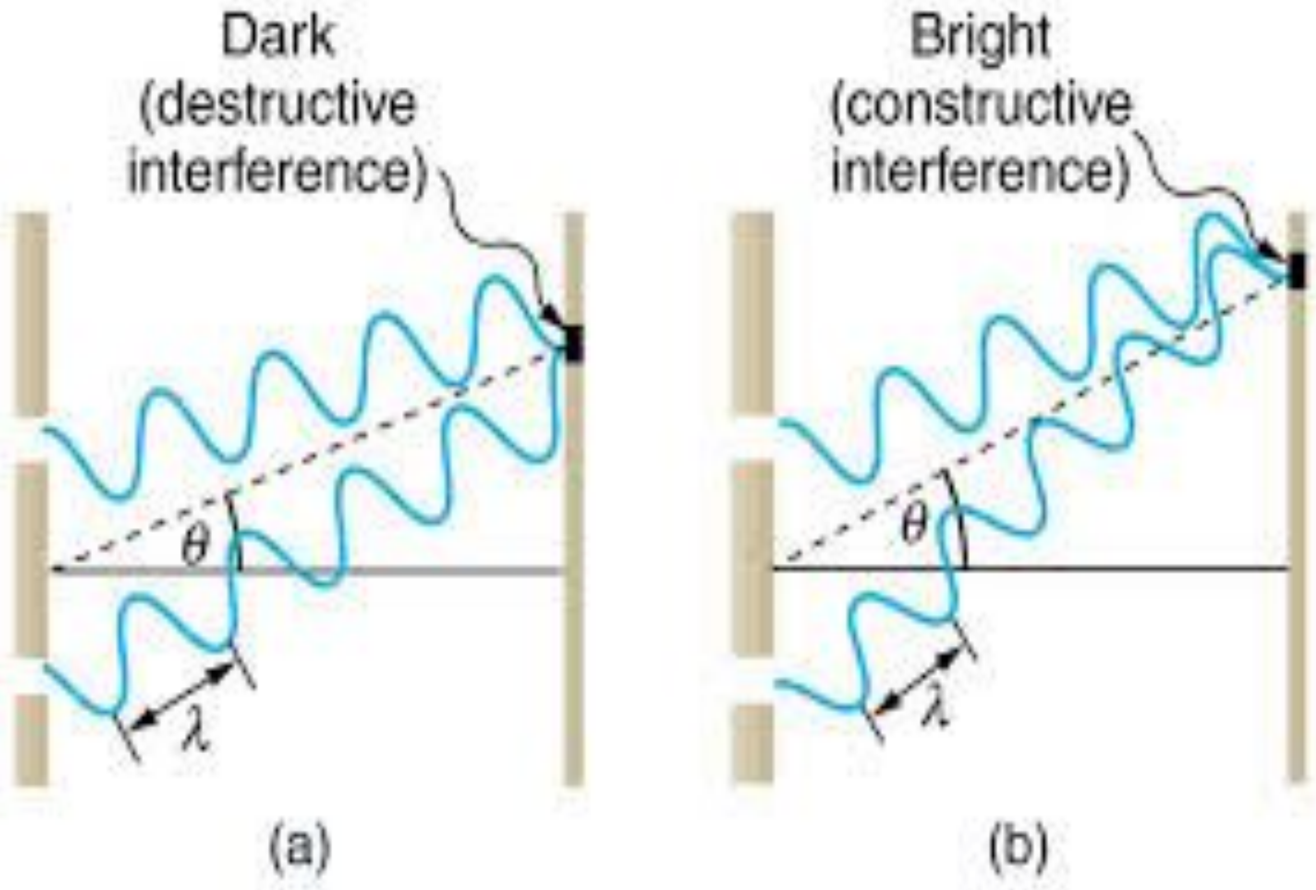
      A) $A_{tot}=A_1+A_2$

3) "index-of-refraction" n: $c'=c/n$; $\lambda'=\lambda/n$ ($f=f'$); $n_{vacuum}=1$

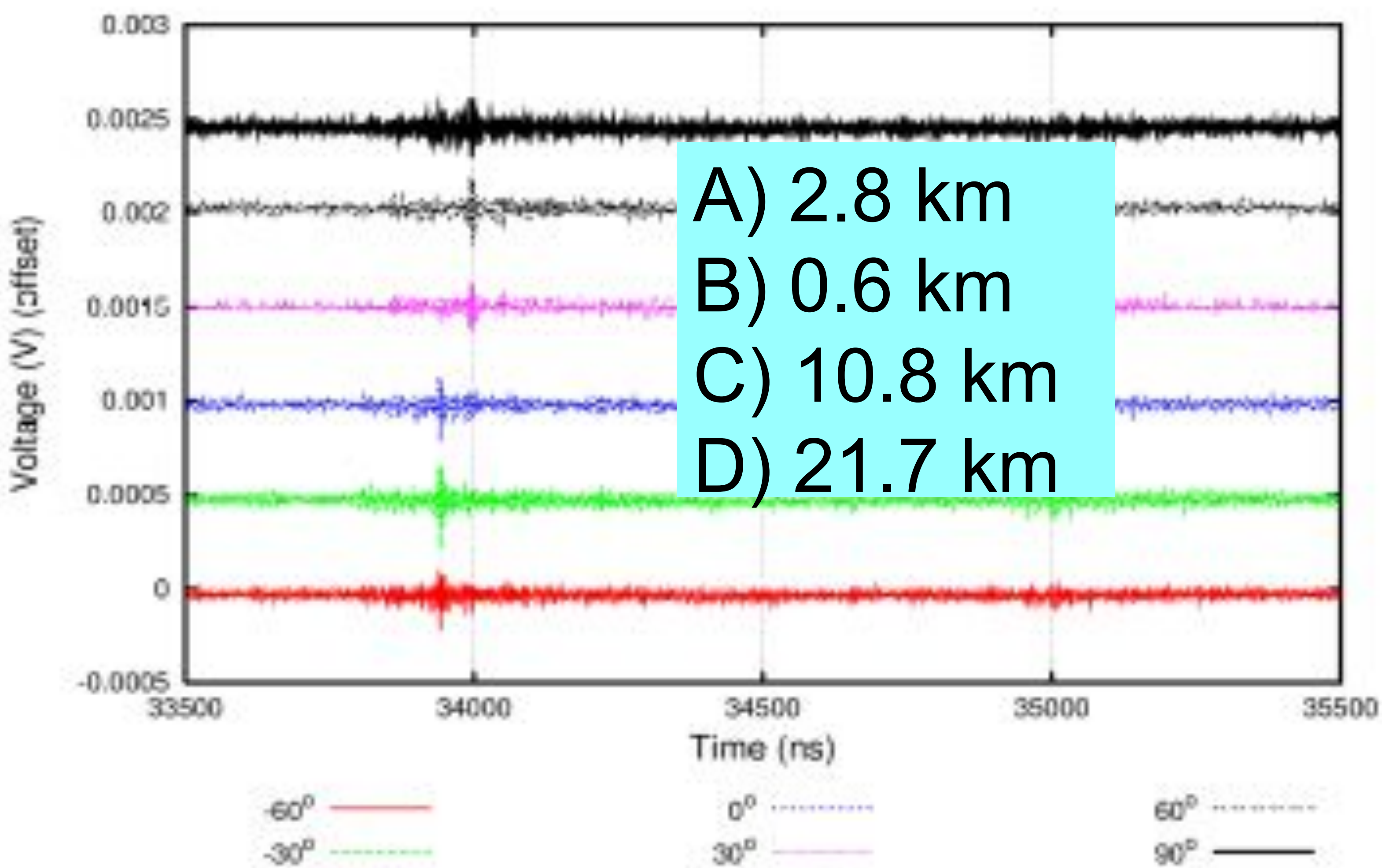
   A) Waves travel more slowly if $n>1$

   B) Waves 'refract' when crossing from $n_1 \rightarrow n_{2;}$ $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Which of the following would increase the spacing between maxima on the screen? A) Increasing the slit distance, B) Increasing the wavelength, C) Both A) and B) D) NOTA



What is the ice thickness at South Pole based on the radar data below (n_{ice}=1.75)?



A) 2.8 km
B) 0.6 km
C) 10.8 km
D) 21.7 km

Assuming a single source, the minimum thickness of polycarbonate (n=2) for which radio waves of frequency 150 MHz give zero intensity (darkness) at a pt 8 m away is:

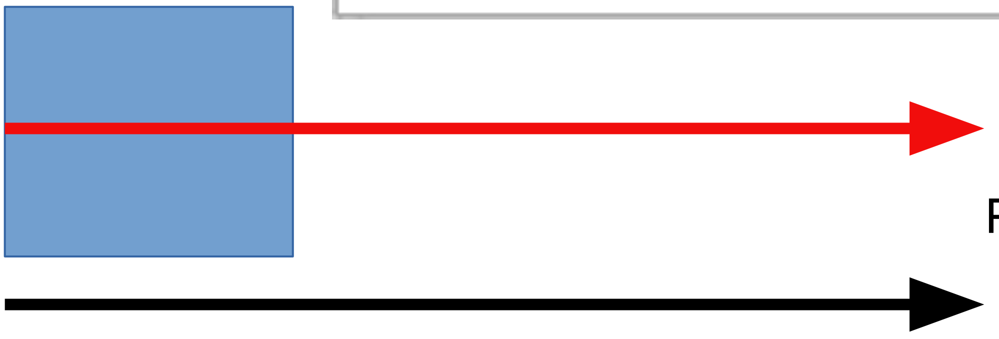
A) 2.33 m

B) 3 m

C) 1 m

D) 2 m

E) NOTA



Assuming a single source, the second smallest thickness of polycarbonate (n=2) for which radio waves of frequency 300 MHz give zero intensity (darkness) at a pt 8 m away is:

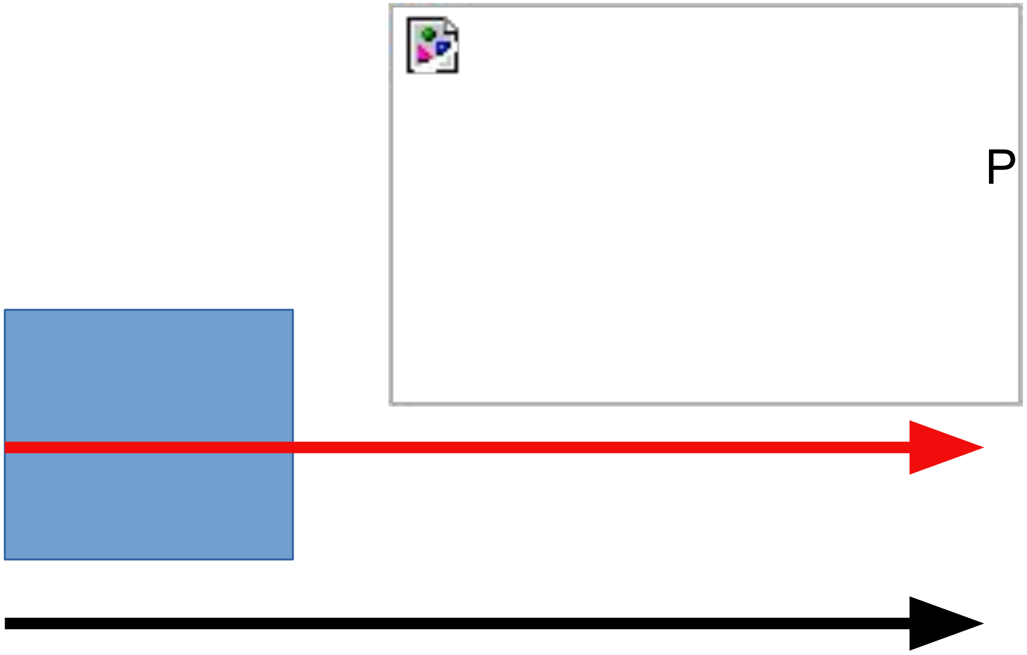
A) 2.33 m

B) 0.5 m

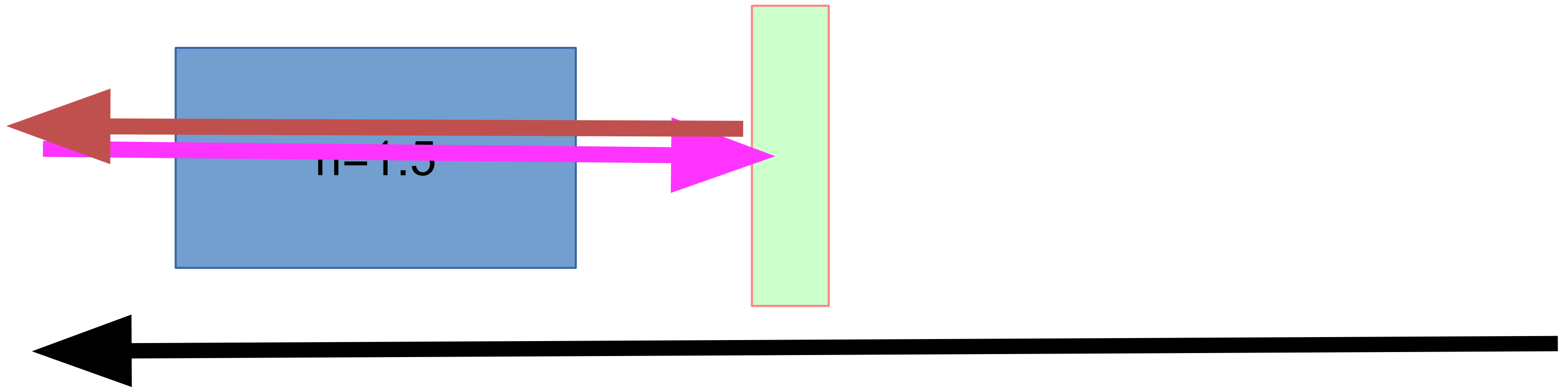
C) 1 m

D) 2 m

E) NOTA



Now a mirror is placed, as shown, so the interference is between one reflected wave, and one direct wave. t_{min} for constructive interference at a point 8 m to the left of the mirror is (assume the rays are emitted in phase, and both travel a total distance of 16 m)



A) 1 m

B) 2 m

C) 0.5 m

D) 4 m

E) NOTA

If the two sources oscillate out-of-phase at 50 MHz, find the minimum non-zero thickness of glass (n=2) such that P is 'dark', given that d=24 m

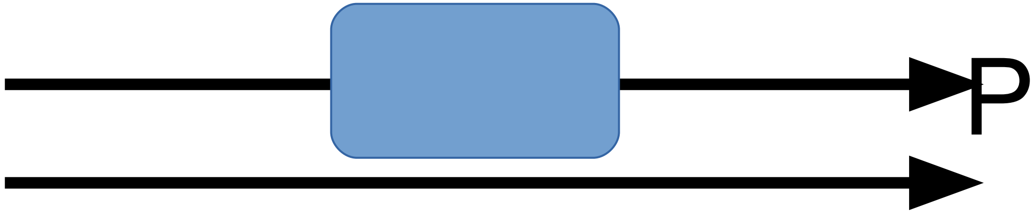
A) 1 m

B) 6 m

C) 12 m

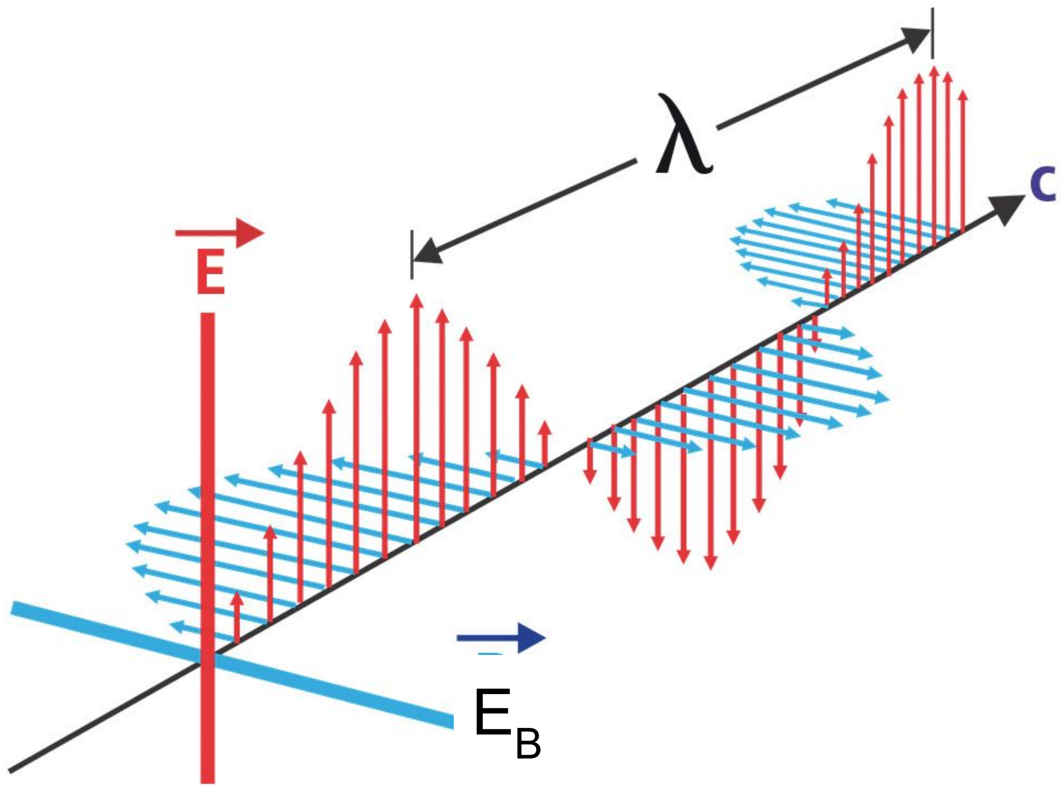
D) 24 m

E) NOTA



If wave A is polarized in the y direction and wave B is polarized in the x direction, the intensity of A+B, relative to A only is:

A) 1
B) 2
C) 4
D) 8
E) NOTA



You look down at an oil slick on water and see a bright yellow (λ=600 nm) circle. Assuming 'normal' incidence, what is the next larger thickness which results in a bright color?

A) 450 nm

B) 300 nm

C) 200 nm

D) 100 nm

E) NOTA

You look down at an oil slick on water and see a bright yellow (λ=600 nm) circle. Assuming 'normal' incidence, what is the next smaller wavelength which appears bright?

A) 400 nm

B) 300 nm

C) 200 nm

D) 100 nm

In the previous problem, as you moved further from 'normal' incidence, the spacing between bright colors would get:

A) Smaller

B) Larger

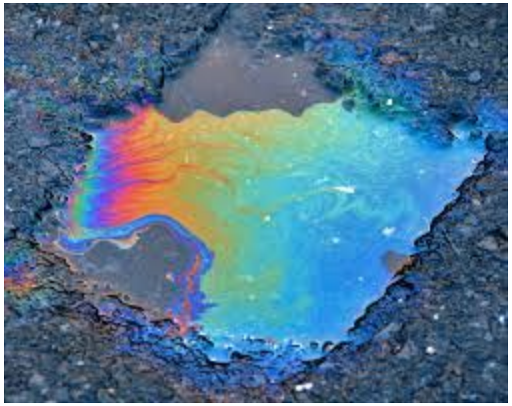
C) Be unchanged

What would have the effect of making the colors 'closer' in the oil slick shown?

A) Making the oil slick thicker

B) Increasing index-of-refraction of oil

C) Decreasing index-of-refraction of underlying water

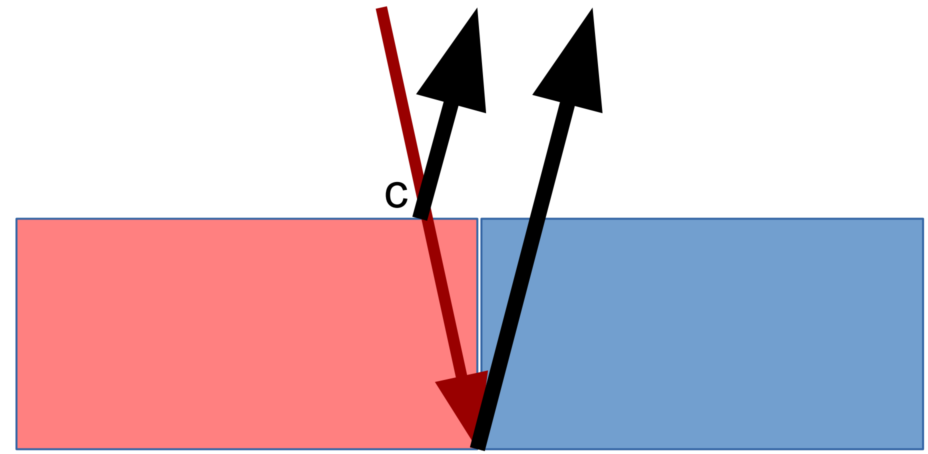


Yellow light ($f=5 \times 10^{14}$) shines (starting in air) on a 600 nm thick film with $n_1=2$ on the left, and $n_2=1.5$ on the right, on top of air, nearly vertical. By tracing out crests and troughs, the interference at the observer is:

A) Constructive

B) Destructive

C) Halfway between constructive and destructive



What is the total time required for the light that refracts to travel through the pink/blue blocks?

Observing a bright blue ($f=7.5 \times 10^{14}$/sec) circle on an oil slick ($n_{oil}=2$) sitting on top of water ($n=1.5$), you would conclude that the oil slick has a minimum thickness of:

A) 100 nm

B) 200 nm

C) 450 nm

D) 50 nm

E) NOTA

Observing a bright blue (λ=400 nm) circle on an oil slick sitting on top of glycol (n_{glycol}=2.5), you conclude that the oil slick has a minimum thickness of:

A) 100 nm

B) 200 nm

C) 450 nm

D) 50 nm

E) NOTA

if n_1=2, n_2=1.25 and n_3=2.5, and if the frequency is $3x10^{14}$, the second smallest thickness for constructive interference is:

A) 600 nm

B) 200 nm

C) 450 nm

D) 800 nm

E) NOTA

In the previous problem, what is the minimum thickness for 'darkness'?

MM expt: Given two trains, one moving at v_x=+20 km/s and another moving at v_x=-40 km/s. At the time they cross each other at x=0, each fires a bullet* at observer O at x=+80 km. How much earlier does the bullet from train 1 arrive?

A) 2 s

B) 0.8 s

C) 2.8 s

D) 1.2 s

E) NOTA

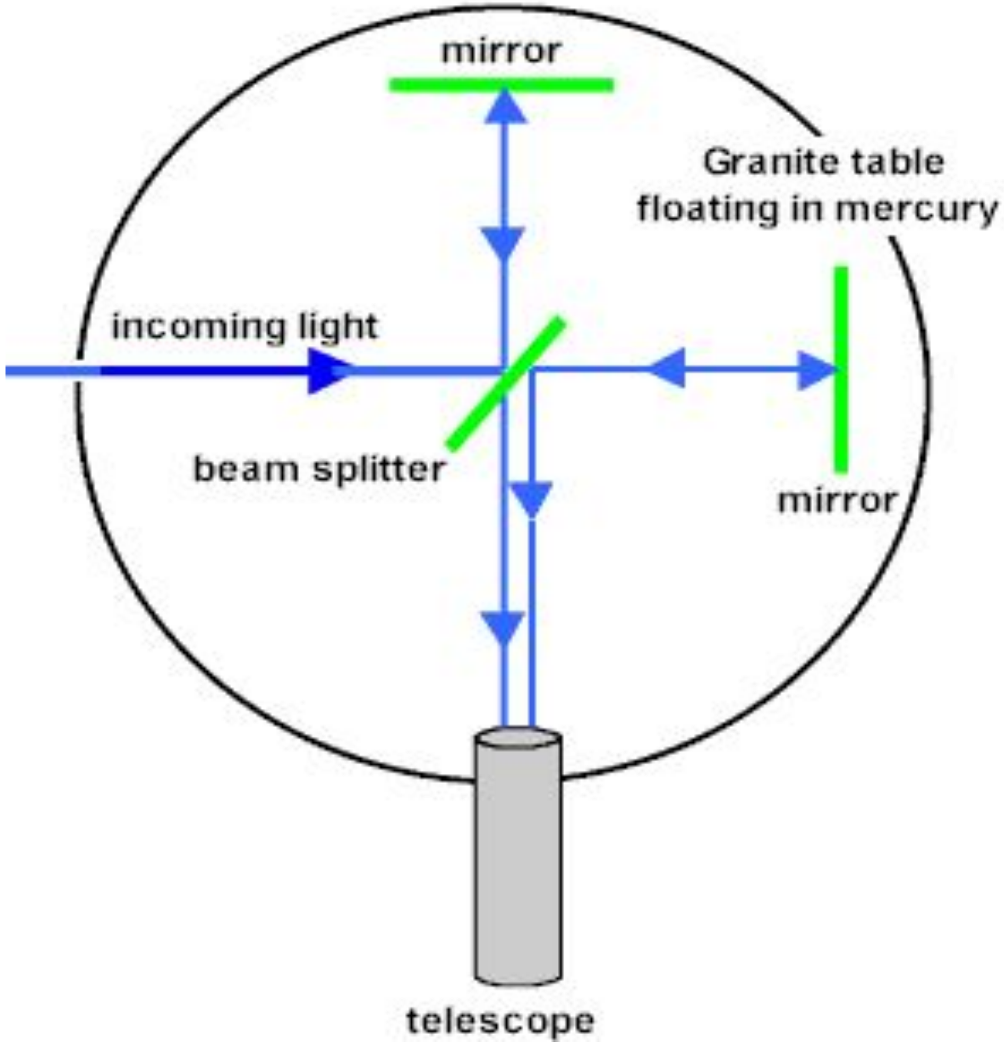
Now allowed in your coat pocket in our phsx class!

In the Michelson-Morley expt., with v_x =+300 km/s, and given d_1=d_2=300 m which ray arrives at the telescope first?

A) Vertical ray

B) Horizontal ray

C) They arrive at the same time



A 400 MHz F_y=6 N force acts on a +2 C, 1 kg charge at (0,0), an identical *in-phase* force, but at 300 MHz, acts on a 3 C, 1.5 kg charge, at x=-1. At x=2, the ratio $|E_{rad,1}|/|E_{rad,2}|$=

A) 1.5

B) 1.0

C) 0.75

D) 0.66

E) NOTA

At $x=2$ m and $t=10^{-9}$ s, the ratio of intensity from charge 1 only to the net intensity from both charges is:

A) 0.230

B) 0.193

C) 0.108

D) 0.914

E) NOTA

In the previous problem, if the second source was oscillating out-of-phase, then the ratio of intensities would be:

A) 0.230

B) 0.193

C) 0.108

D) 0.914

E) NOTA

In the previous problem, if the second source charge was negative, then the ratio of intensities would be:

A) 0.230

B) 0.193

C) 0.108

D) 0.914

E) NOTA

In the previous problem, if the 3C charge was oscillating in the +/-z direction, what is the new intensity ratio at x=2 m?

A) 0.230

B) 0.193

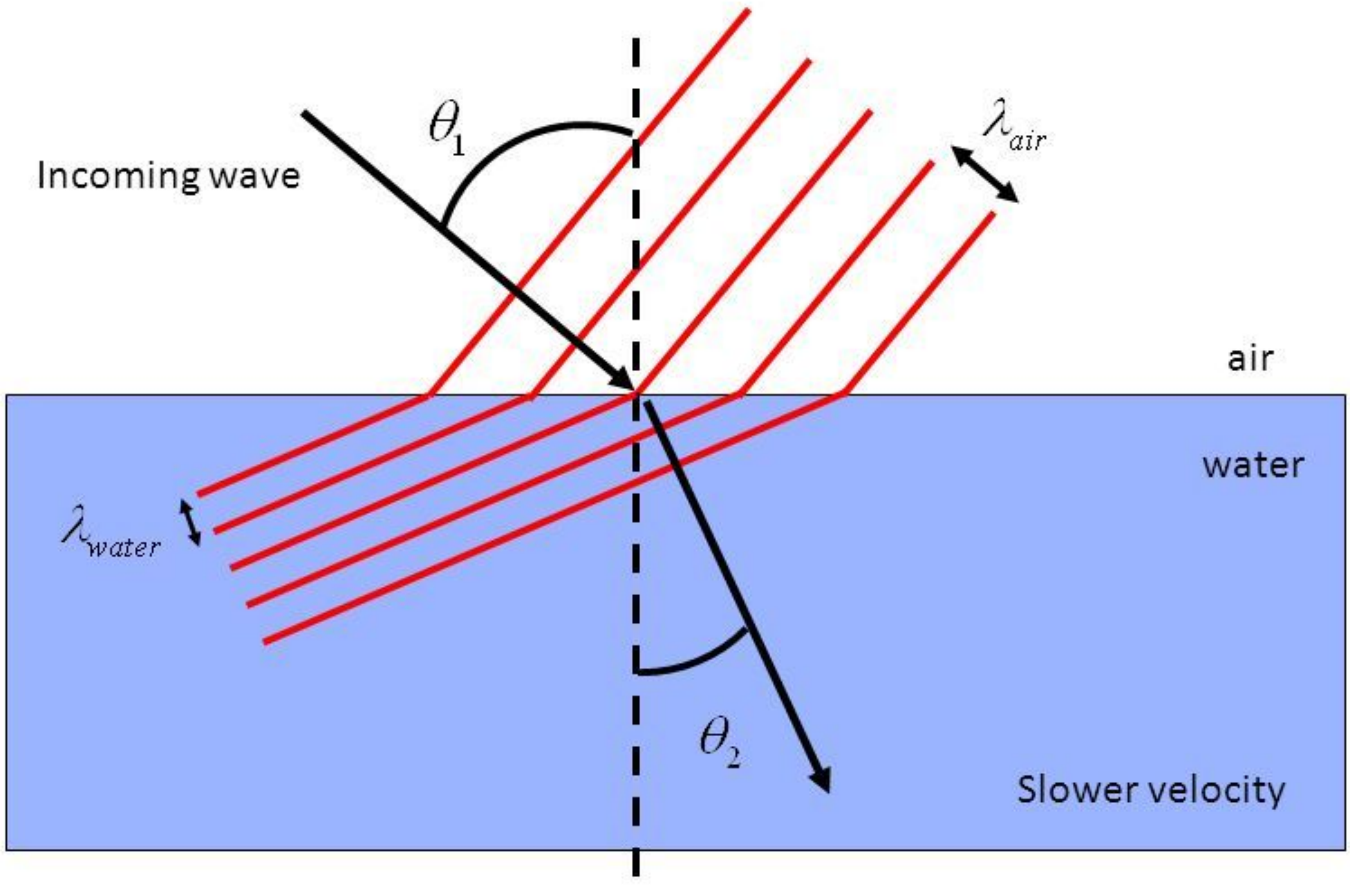
C) 0.108

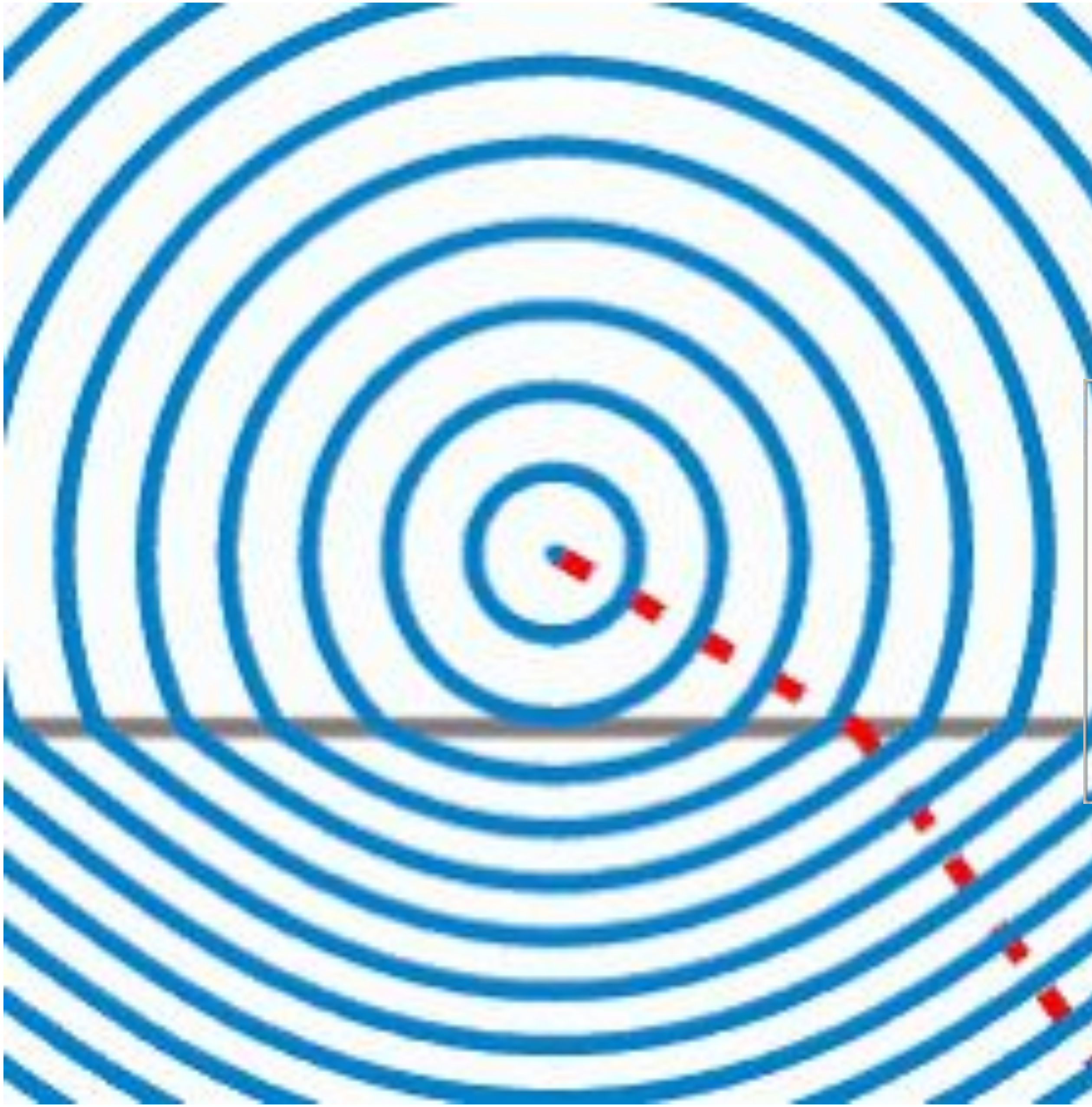
D) 0.914

E) NOTA

Refraction

Refraction: bending of a wavefront at a boundary between two media, due to the change in velocity





Suppose the incident ray is at a crest as it intercepts the surface, the phase of T3 and T5 are

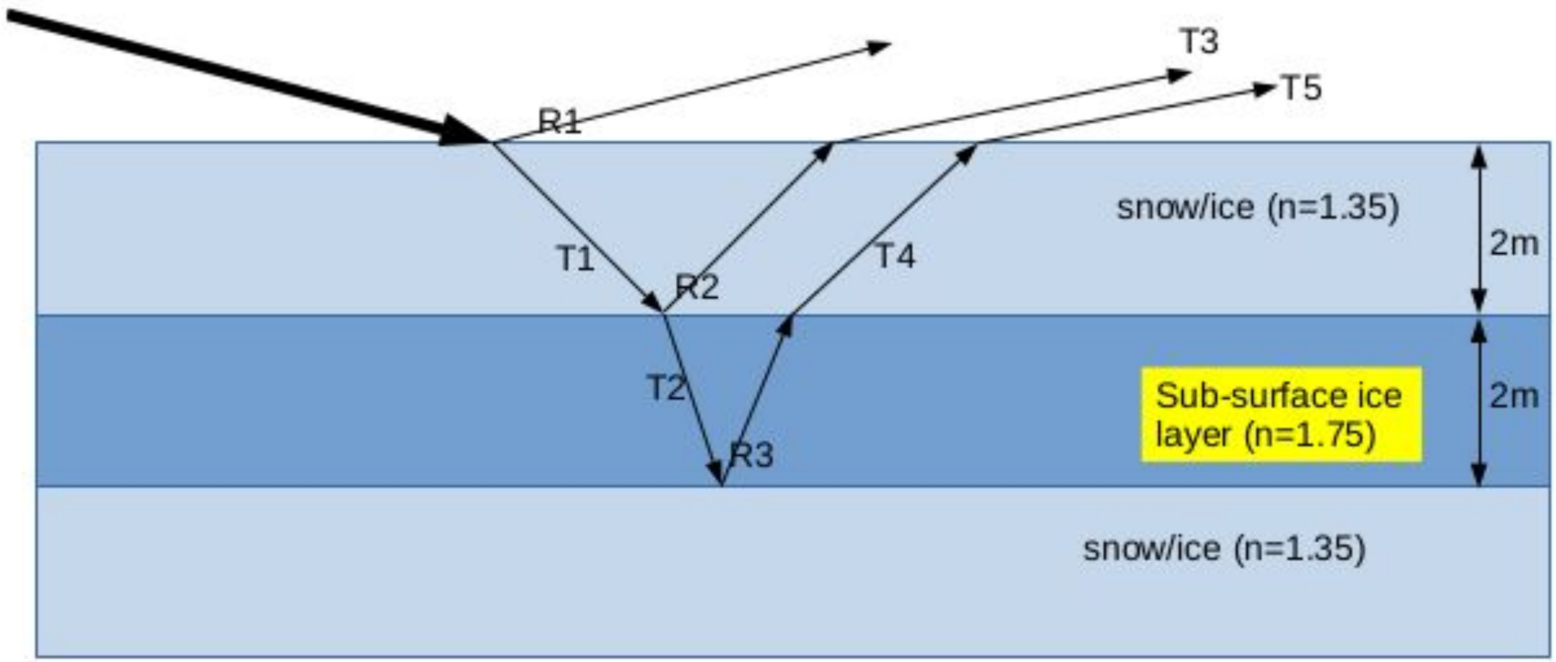
A) Crest, trough

B) Crest, crest

C) Trough, trough

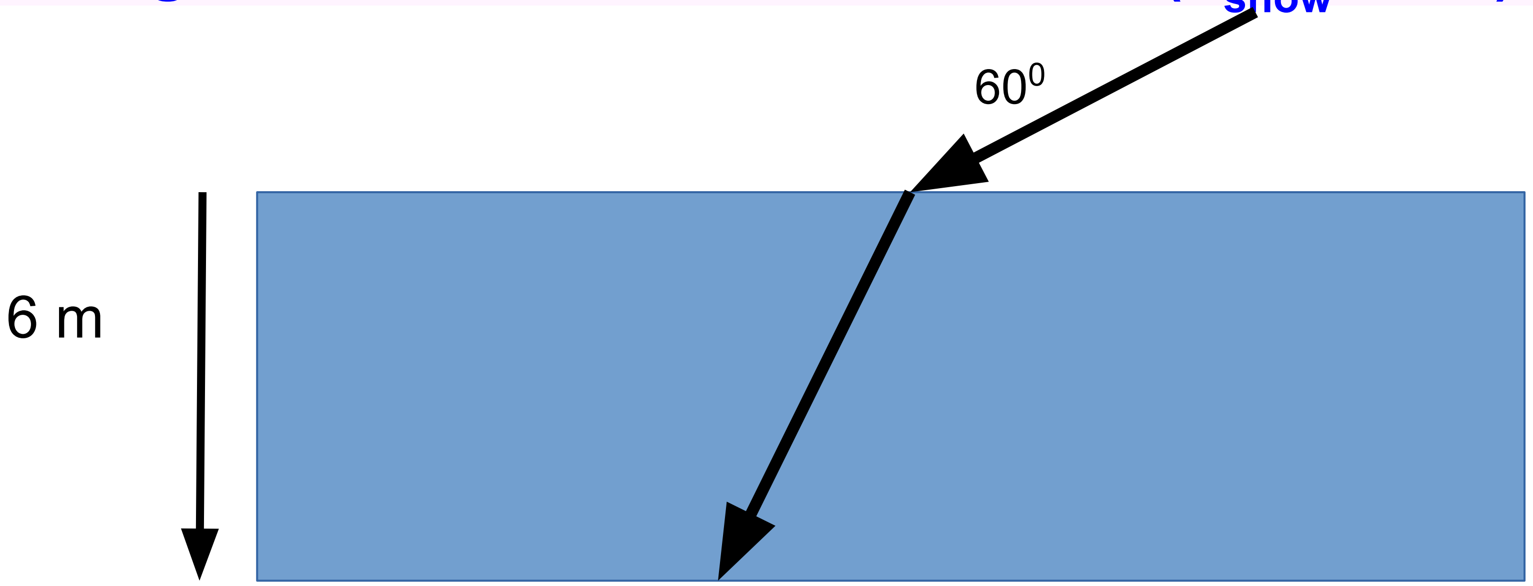
D) Trough, crest

E) NOTA



Speculation to explain 'mystery' events:
Maybe there is an embedded ice layer within the Antarctic ice sheet?

A 600 MHz radio wave is incident from air into a 6 meter thickness of snow, at a 60° angle relative to vertical ("normal"). The total number of wavelengths the wave travels in snow is: (n_{snow}=1.35)



A) 5.27

B) 6.0

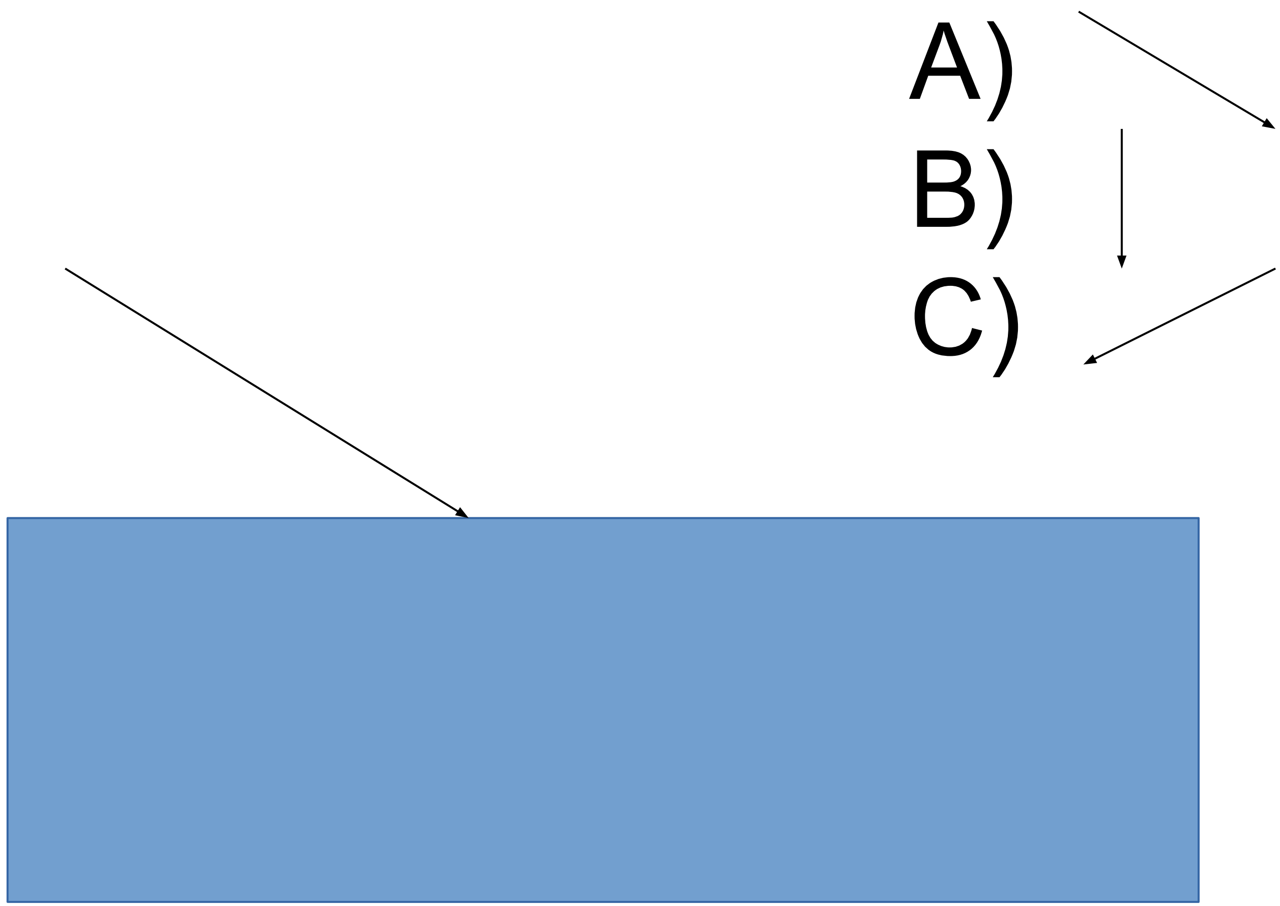
C) 3.0

D) 21.1

E) NOTA

What is the total time required for the wave to travel through the snow?

Given $n_1 \sin\theta_1 = n_2 \sin\theta_2$, which arrow best represents the direction that the ray shown emerges on the bottom side of the glass block (n=1.5)?



If θ_1=53.1° and n_{film}=2 and λ=400 nm, what is the minimum thickness of the film such that the two emerging rays in the upper right are in phase?

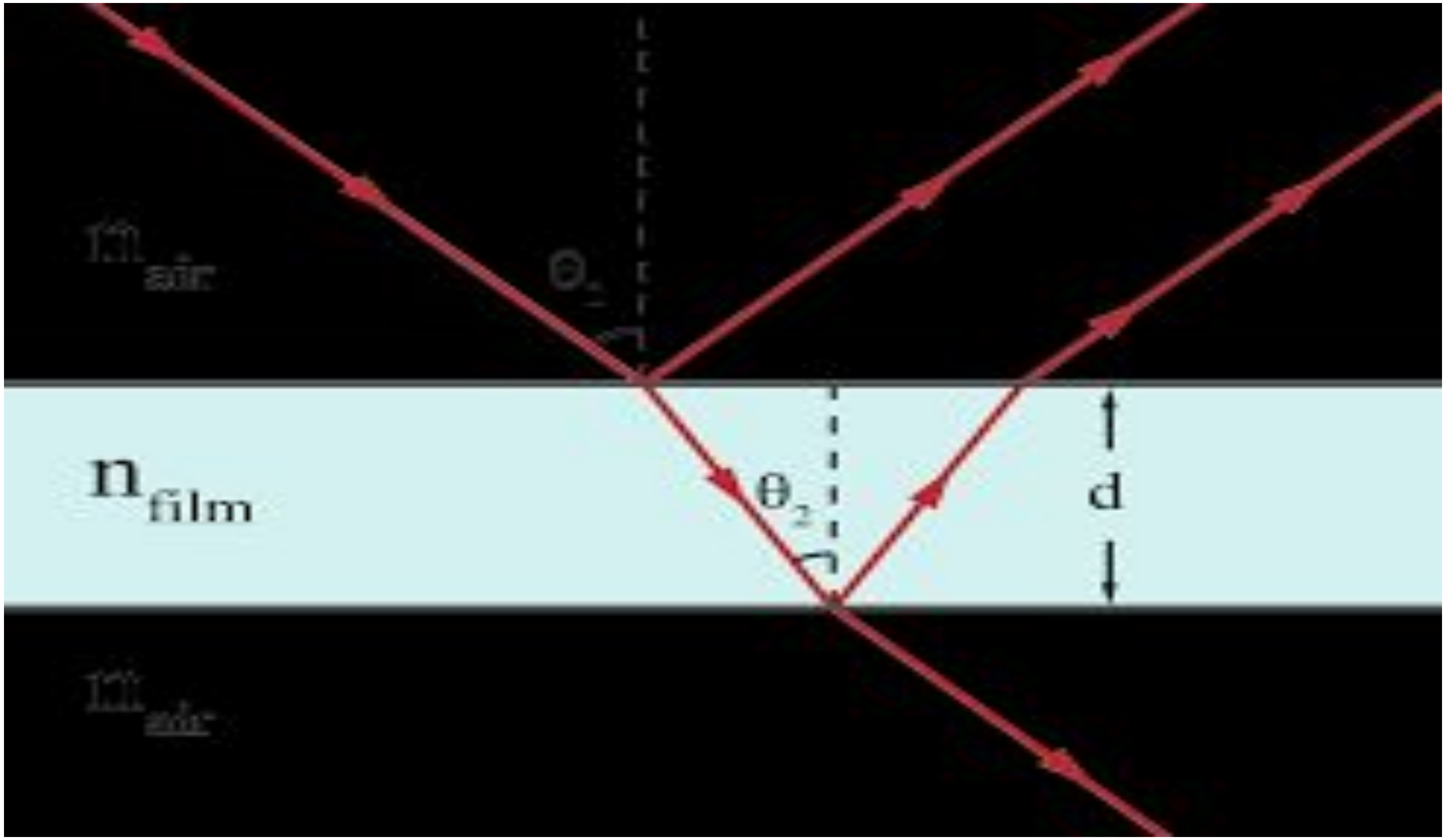
A) 80 nm

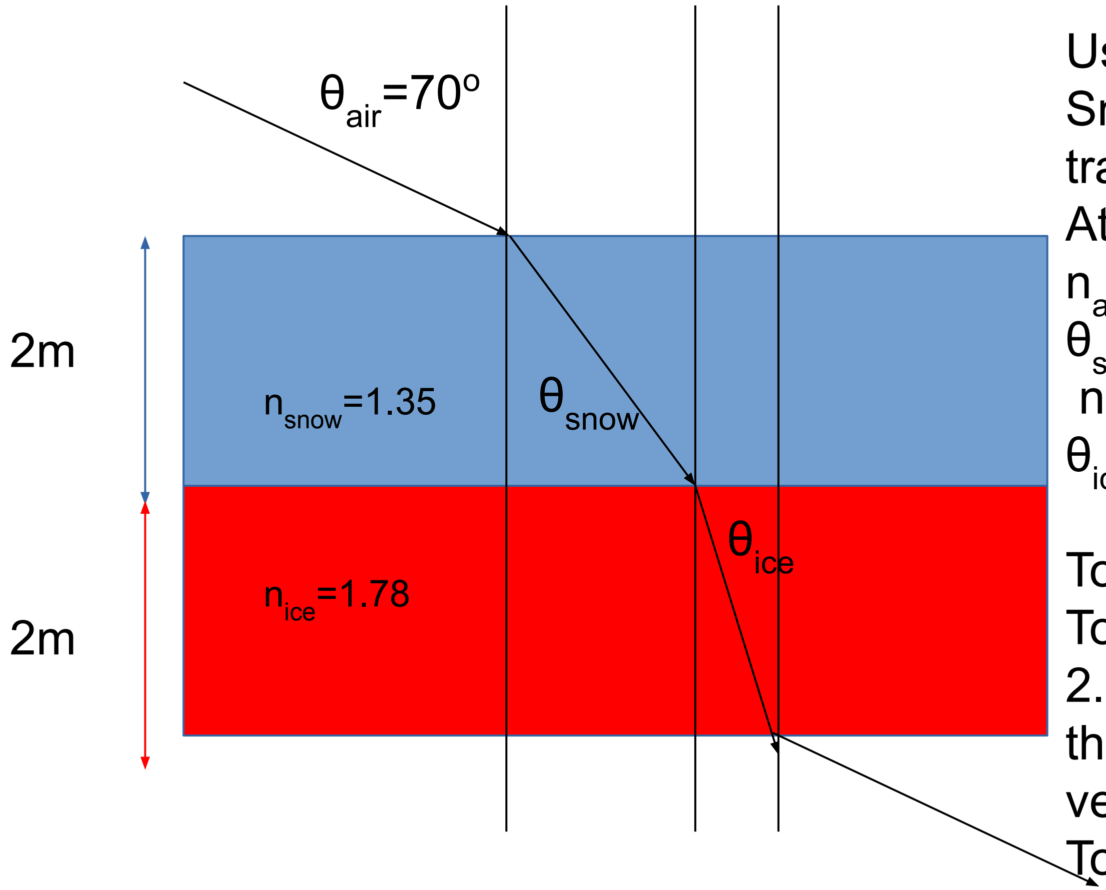
B) 91.5 nm

C) 200 nm

D) 400 nm

E) NOTA





Use geometry + successive applications of Snell's Law to determine angles, distances traveled and propagation times.

At air/snow boundary:

$n_{air}\sin(\theta_{air})=n_{snow}\sin(\theta_{snow})$, solve for θ_{snow}=44.11^o; now input that value to: $n_{snow}\sin(\theta_{snow})=n_{ice}\sin(\theta_{ice})$ to get θ_{ice}=31.86^o

To determine total transit time:

Total distance through snow=2m/cosθ_{snow}= 2.78 meters; similarly, total distance through ice=2 m/cosθ_{ice}=2.35 m (more vertical).

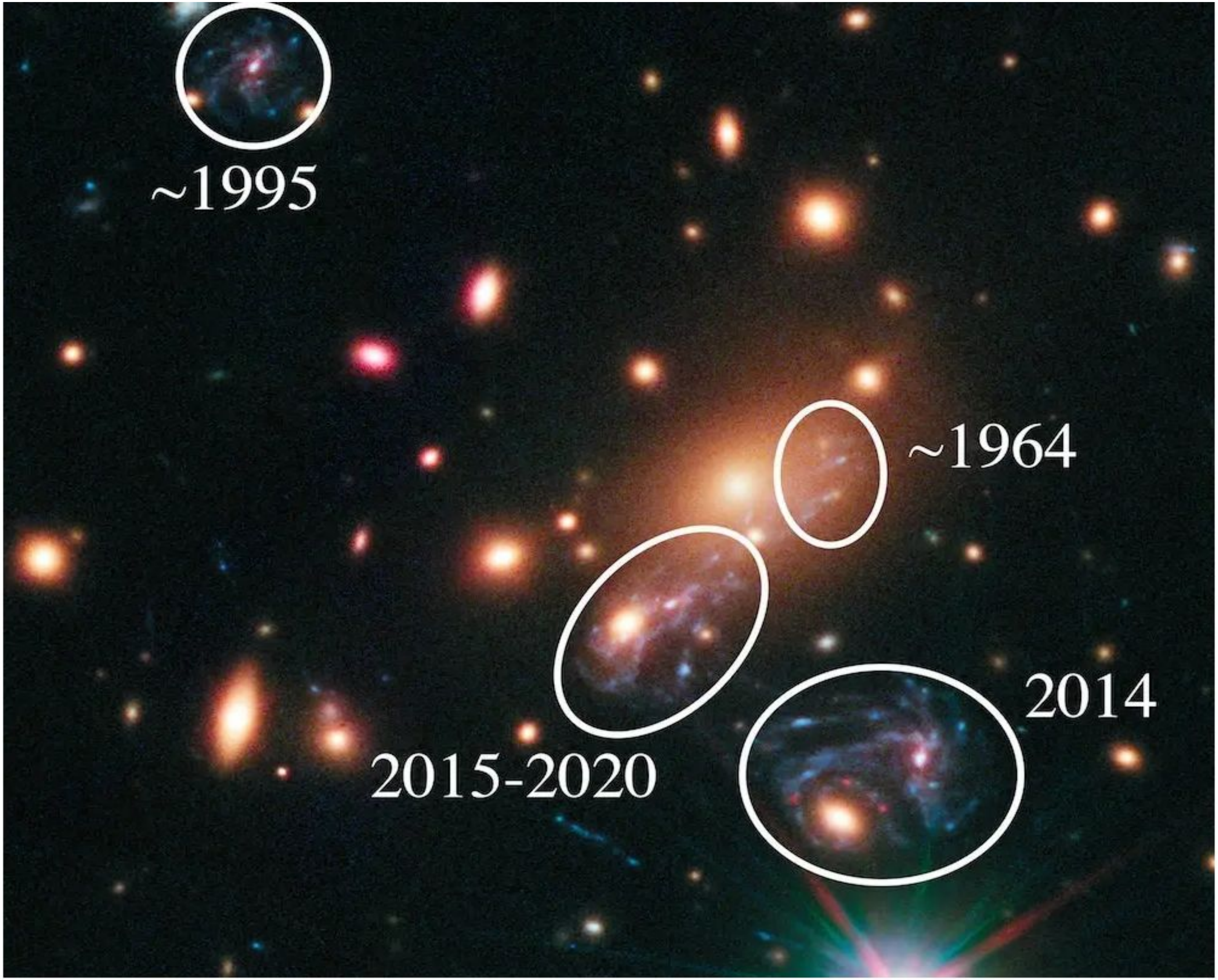
Total travel time=d_{snow}/c +d_{ice}/c =26.45 ns

How many waves over that 4 meter distance? Depends on frequency, since fλ=c. Suppose f=900 MHz, then λ(air)=33.33 cm; λ(snow)=33.33 cm/1.35;

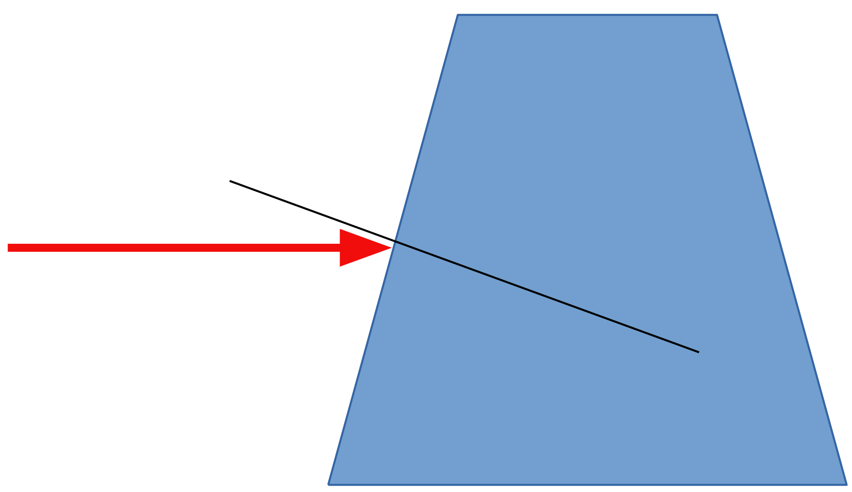
N(waves,snow)=2.78 m/(0.333m/1.35)=11.34 waves

N(waves,ice)=2.35 m/(0.333m/1.78)=12.68 waves (more waves since lower wavelength)

Optics: Dark disk in front of light source.
Center of shadow is brighter/darker than surrounding? (Huygens)
Ray/Geometric optics: Fermat's Least Time principle: $n_1 \sin\theta_1 = n_2 \sin\theta_2$;
lenses and mirrors
focal lengths: positive and negative;
$1/i+1/o=1/f$; $m=-i/o$; focal length determined by crossing-point of horizontal ray with x-axis;
light rays CROSS the normal on refraction


~1995
~1964
2014
2015-2020

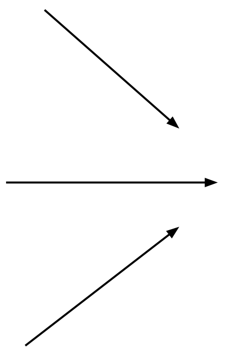
Given $n_1 \sin\theta_1 = n_2 \sin\theta_2$, which arrow best represents the direction that the ray shown emerges on the right side of the glass block ($n=1.5$)?

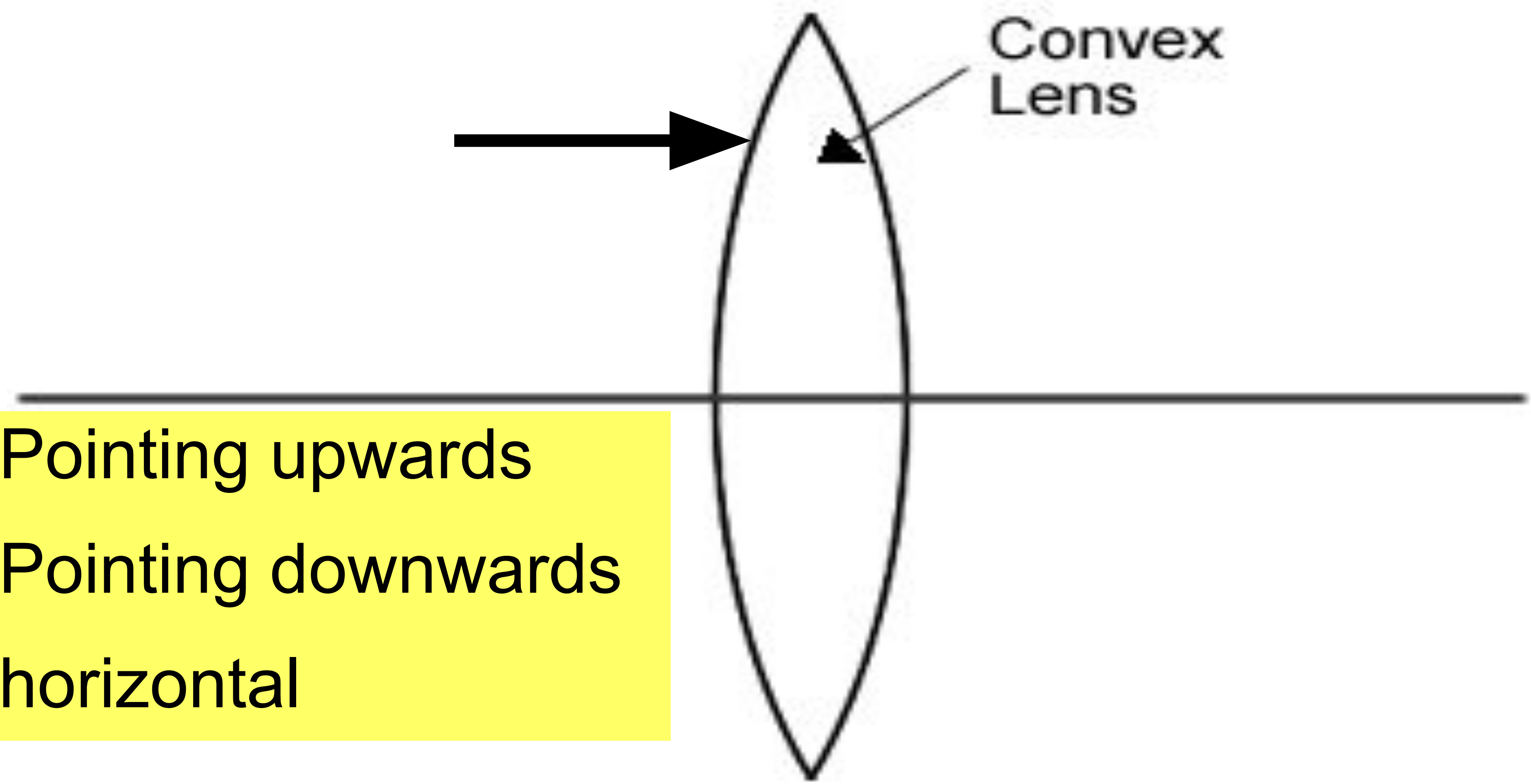


A)

B)

C)



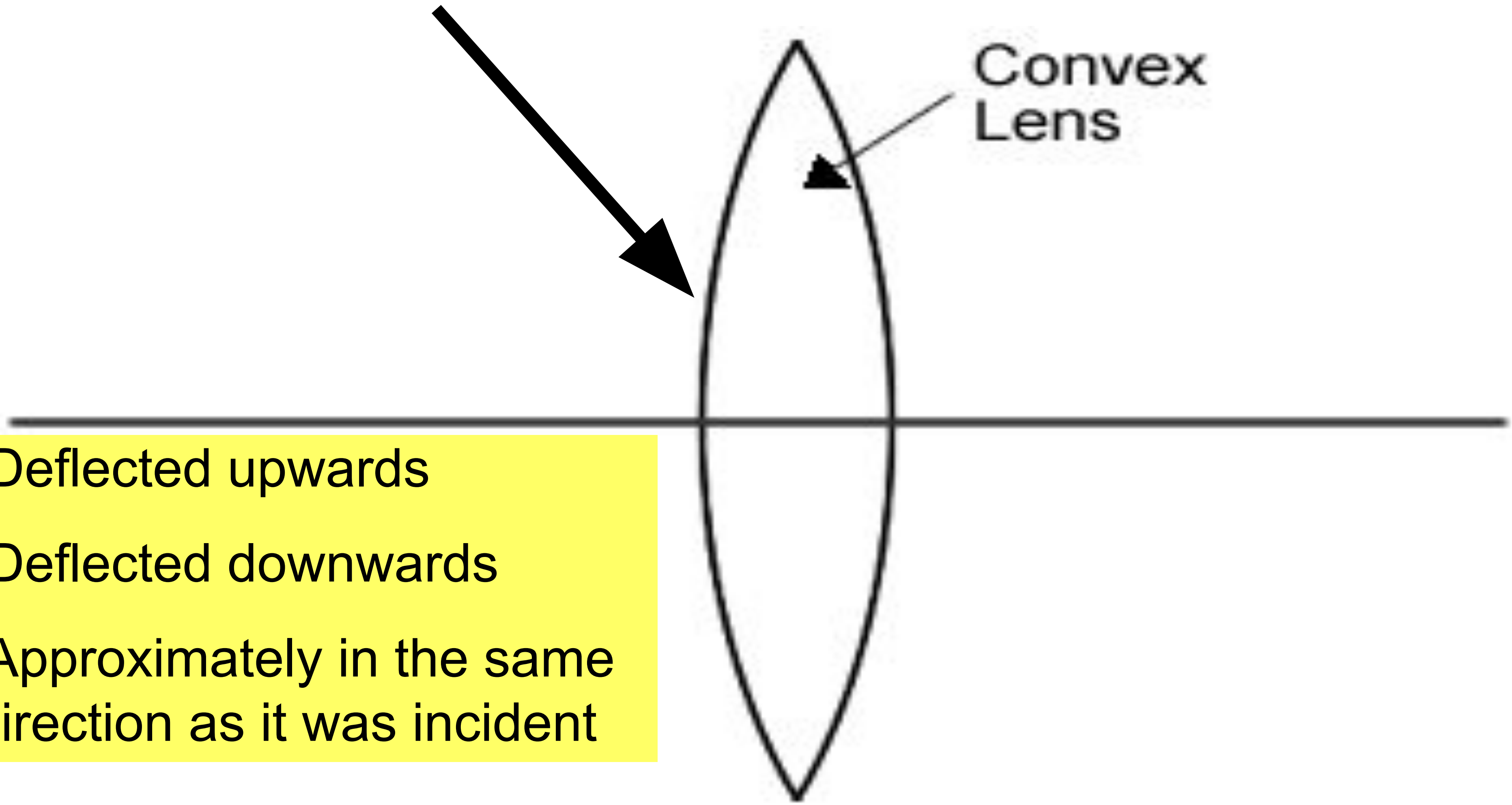


A) Pointing upwards

B) Pointing downwards

C) horizontal

A horizontal light goes from air onto glass (n=1.5) and emerges out the back side. The ray shown emerges:

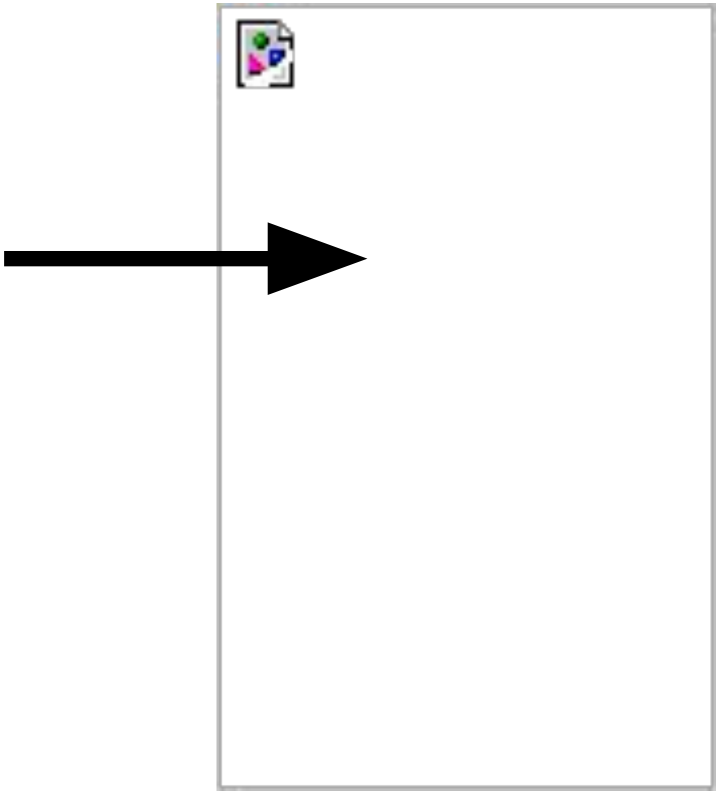


A) Deflected upwards

B) Deflected downwards

C) Approximately in the same direction as it was incident

An angled light ray goes from air onto glass (n=1.5) and emerges out the back side. The ray shown emerges:



A) Pointing upwards

B) Pointing downwards

C) horizontal

Light goes from air onto glass (n=1.5). The ray shown emerges:

Looking down on I-80, you see a 'puddle', from which you conclude:

A) The index of refraction of air increases with temperature

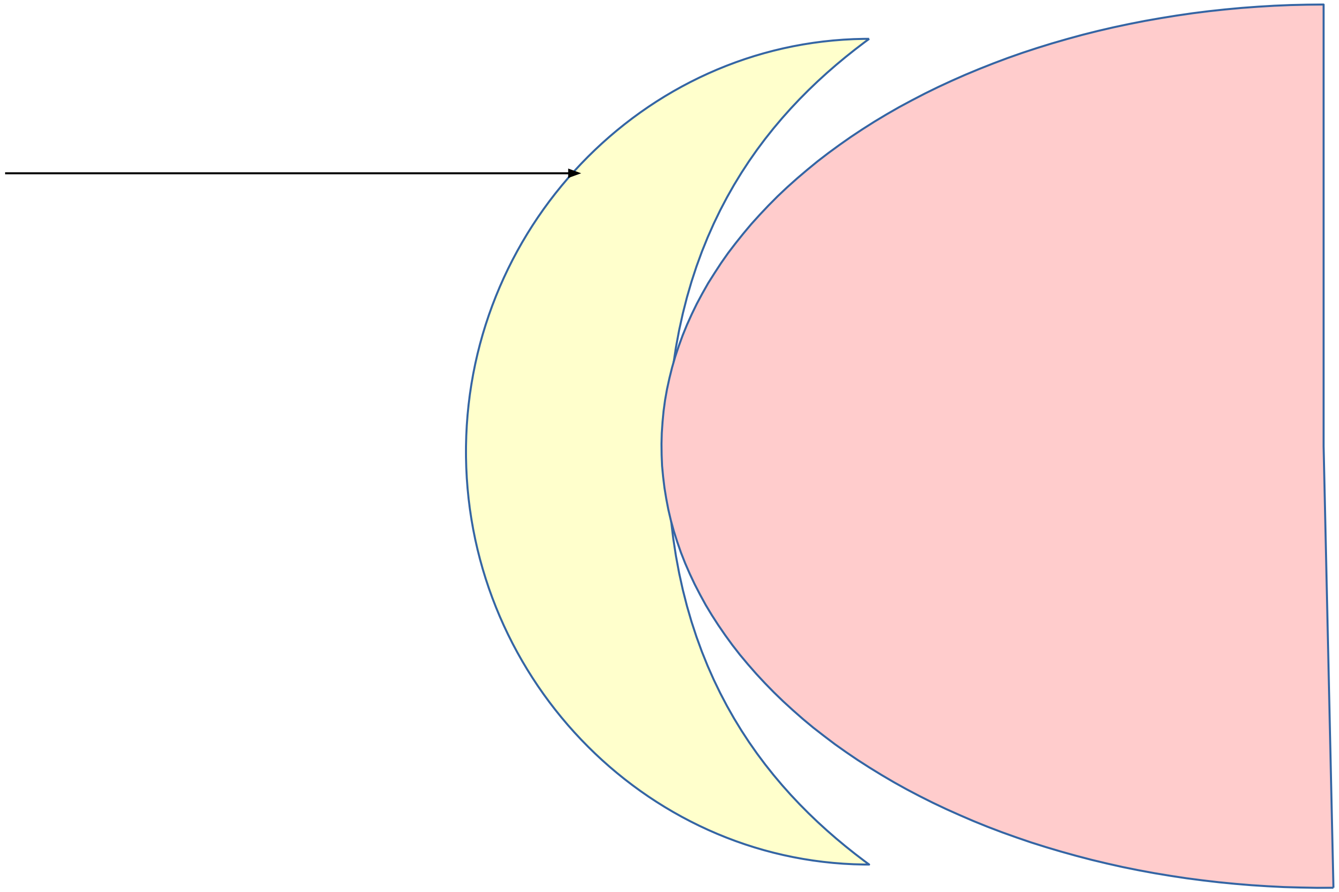
B) The index of refraction of air decreases with temperature

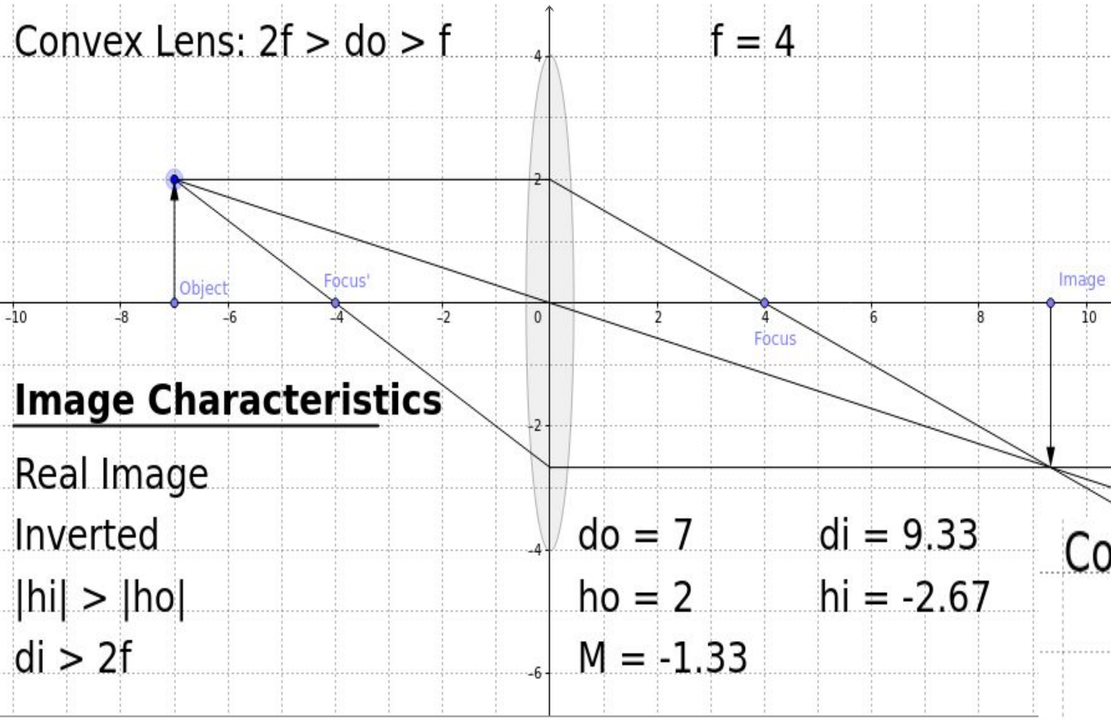
Light is incident from glycol (n=2) onto a plate of glass (n=1.5), in front of a layer of snow (n=1.35). The ray shown emerges:

A) Pointing upwards

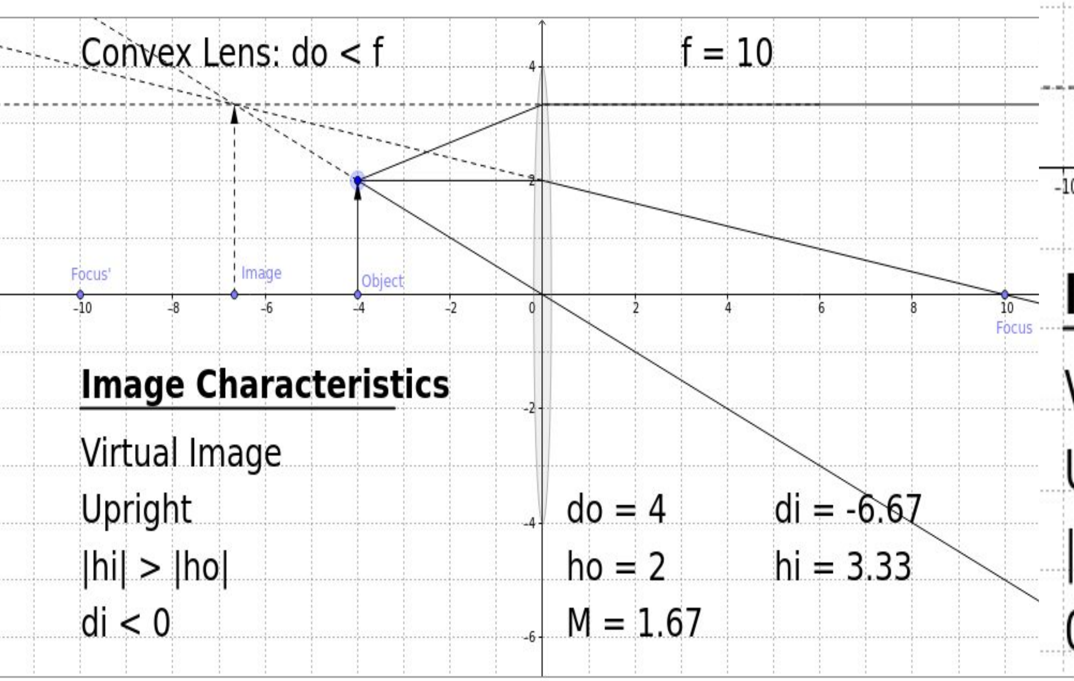
B) Pointing downwards

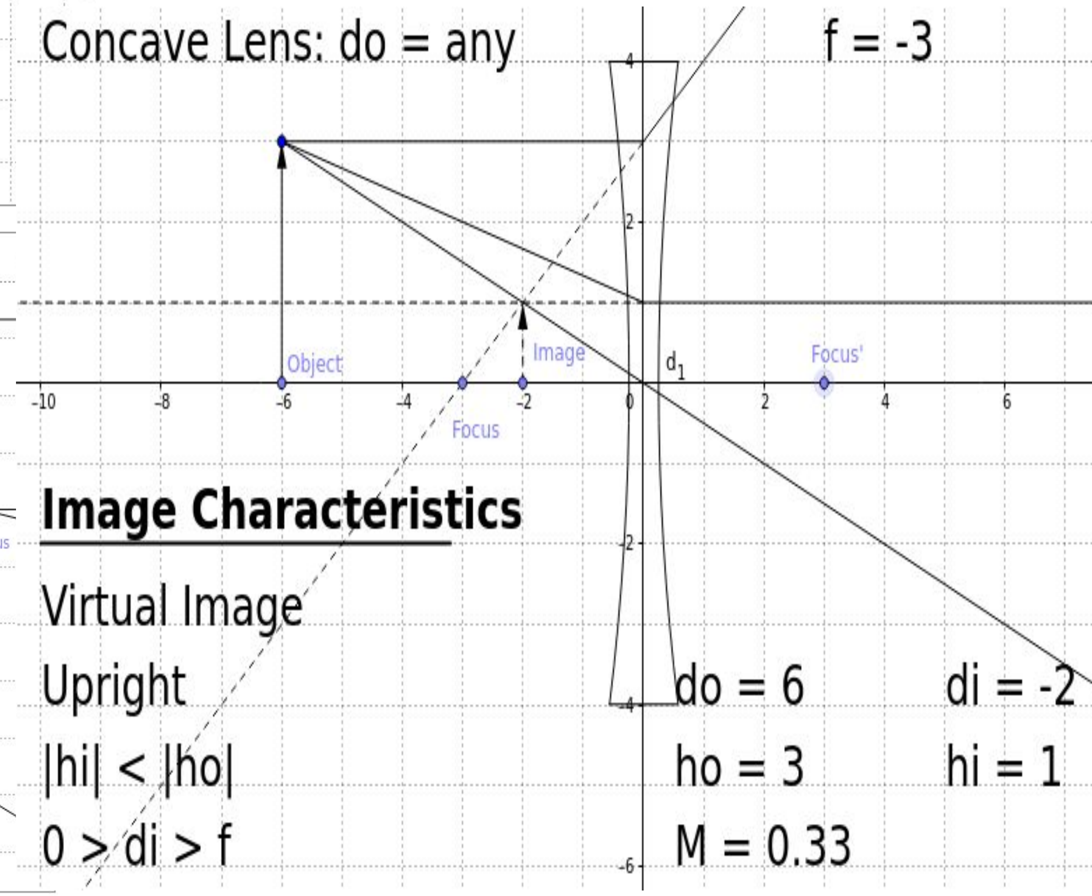
C) horizontal





1/di + 1/do = 1/f
magnification=-di/do
(https://ophysics.com/)





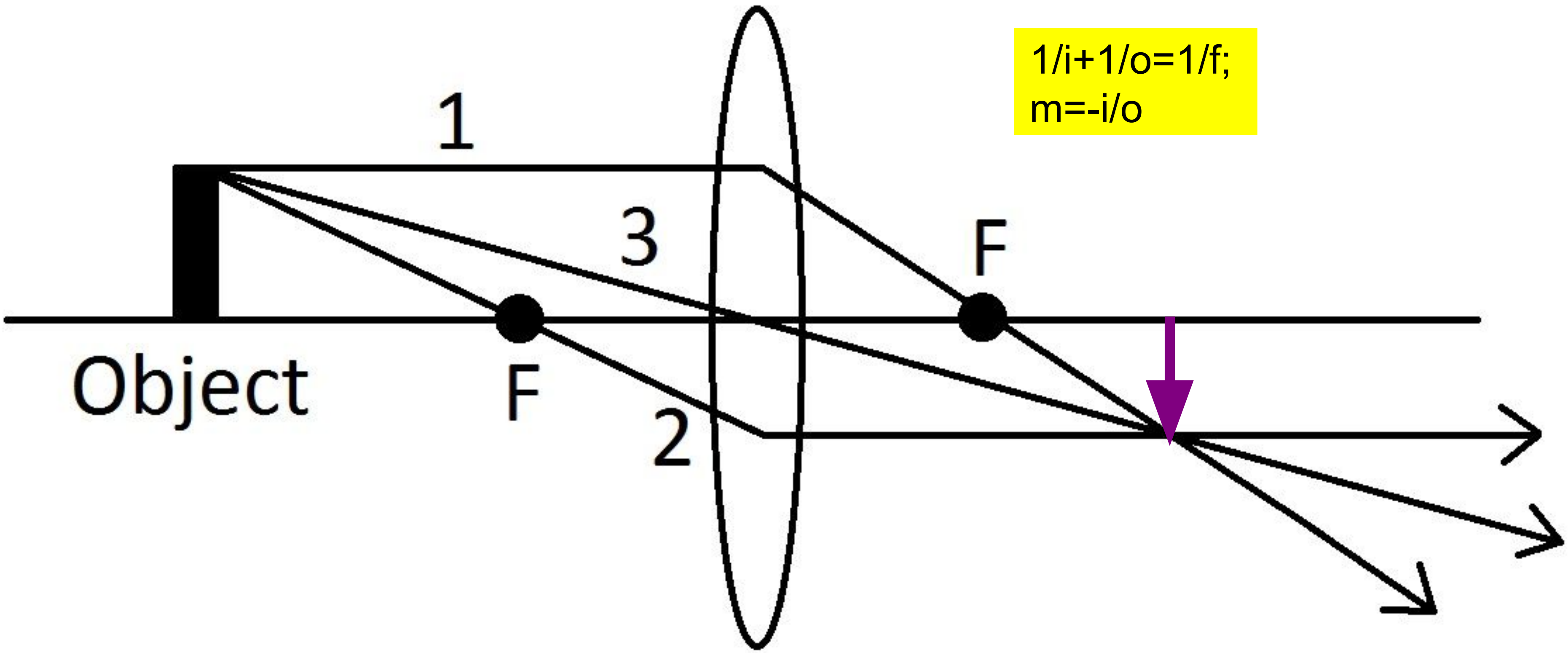
Thin lens formula: 1/i+1/o=1/f

Note human eye has fixed f (ergo, difference b/w diverging and converging corrective lenses).

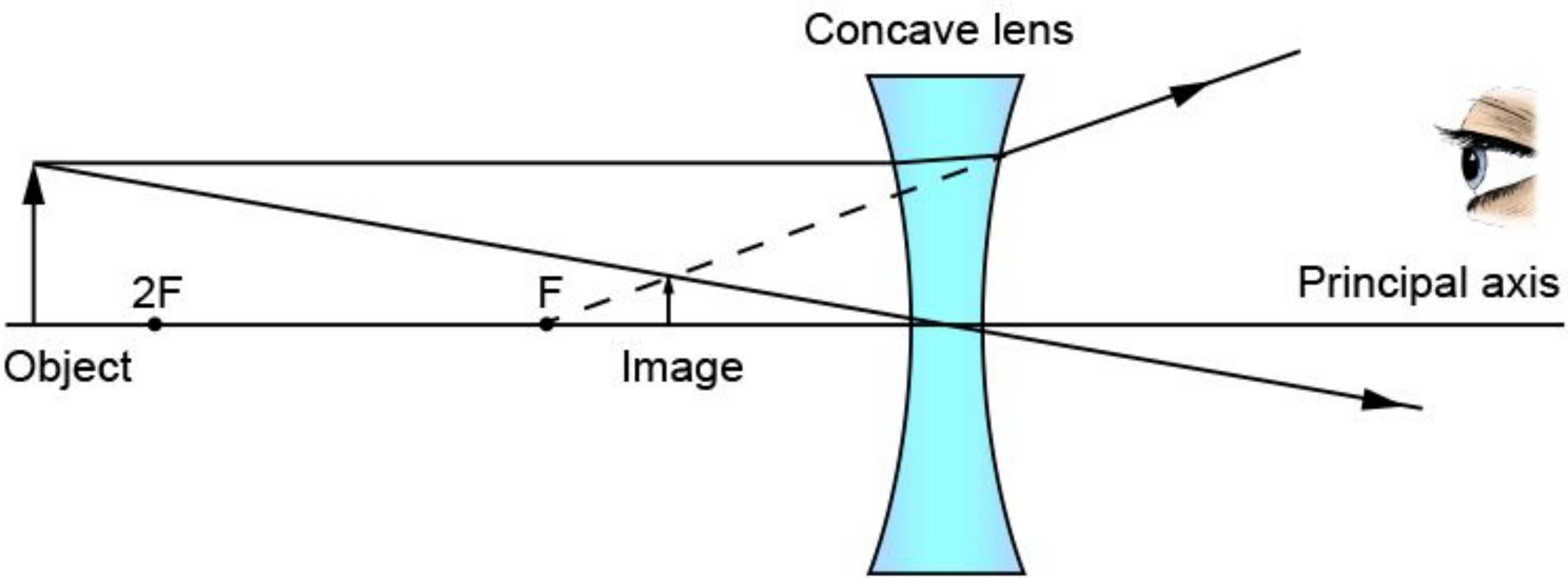
(Lord of the Flies intermezzo)

Double lenses can have either real or virtual second objects (e.g., we see virtual images with our eyes!)

A `lens' is a device which, taking into account the index-of-refraction of the lens and, therefore, how much bending rays entering from air will undergo in the lens itself, has the `right' curvature so that light rays coming from an object will focus at some other point, resulting in an `image'. Here, rays 1, 2 and 3 all originate at the top of the object, and all meet (are 'focused') at the crossing point ("I" or "d_i") shown to the right of F.

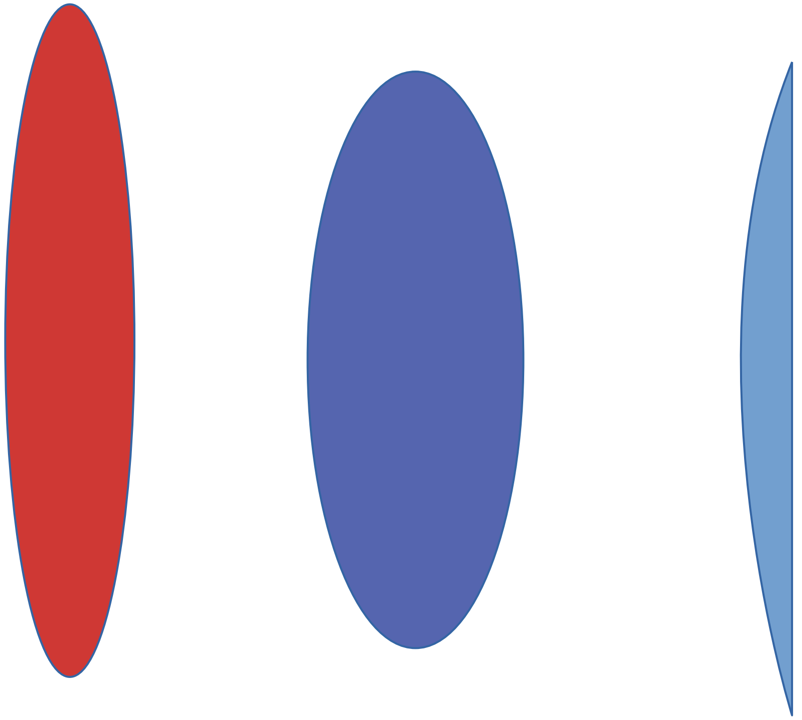


Concave (diverging lens): focal length **negative!**



Rank the lenses shown from smallest to largest focal length.

A) a, b, c
B) c, b, a
C) b, a, c
D) c, a, b
E) NOTA



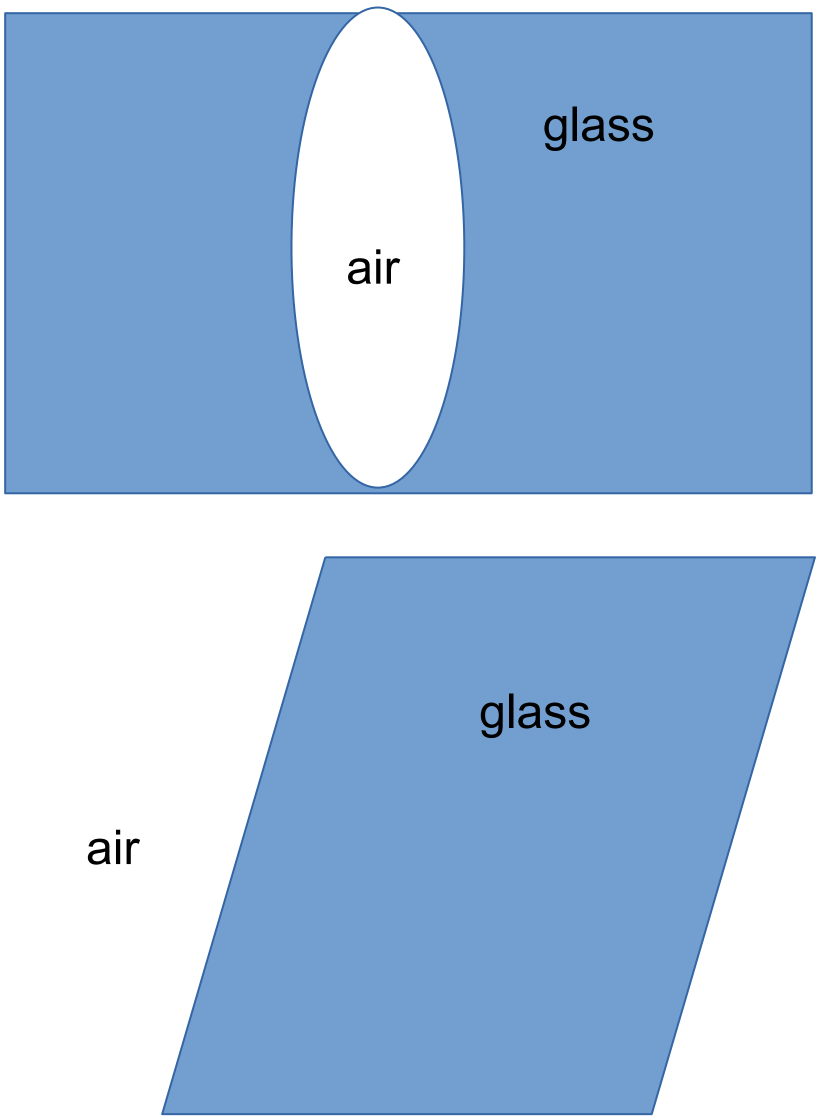
Given the two lenses shown. Which statement is true?

A) Lens 1 has a negative focal length

B) Lens 2 has an infinite focal length

C) Both are true

D) NOTA



A 4 cm tall object is 12 cm from a converging lens with |f|=6 cm. The image formed is:

A) 12 cm tall, upright

B) 12 cm tall, inverted

C) 4 cm tall, upright

D) 4 cm tall, inverted

E) NOTA

$1/i+1/o=1/f$;
$m=-i/o$

If the object is now moved to a distance of 4 cm from the lens, the image formed is:

A) 12 cm tall, upright

B) 12 cm tall, inverted

C) 4 cm tall, upright

D) 4 cm tall, inverted

E) NOTA

As the object moves closer to the lens, the image gets

A) Smaller

B) Bigger

C) Is unchanged

A 4 cm tall object is placed 6 cm from a diverging lens with |f|=4 cm. How large is the image formed?

A) 4 cm
B) 2.4 cm
C) 1.6 cm
D) 0.8 cm
E) NOTA

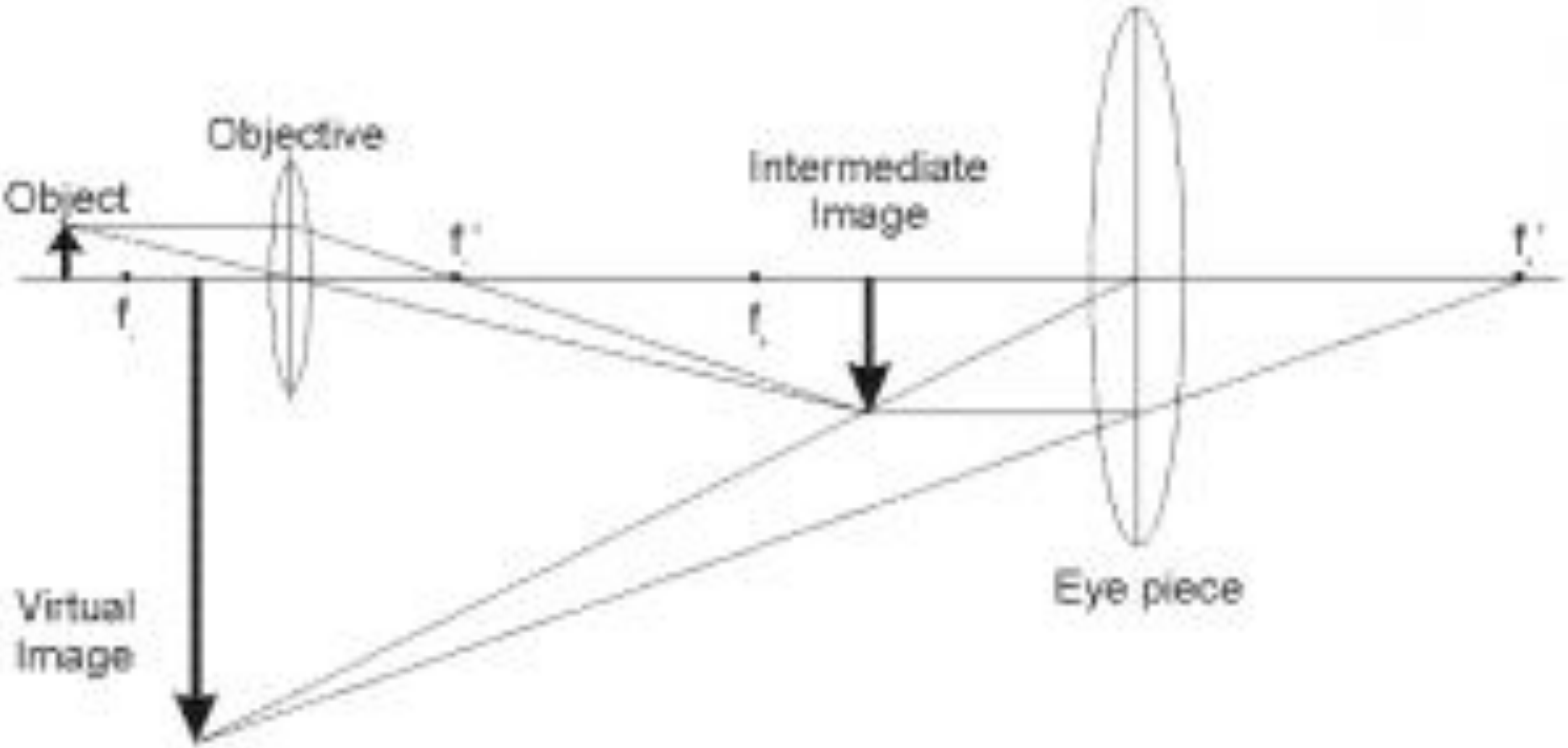
As the object moves closer to the lens, the image gets

A) Smaller

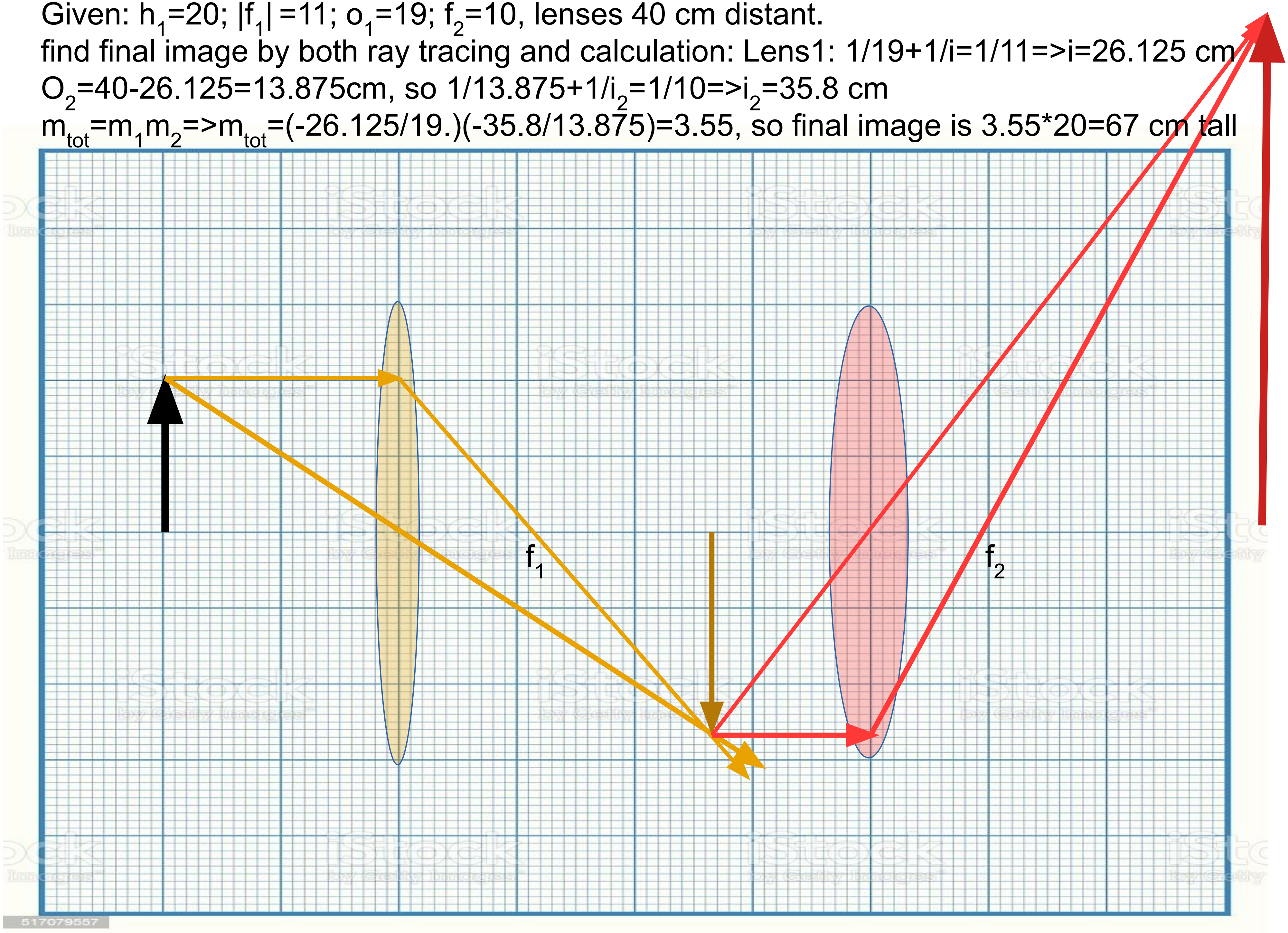
B) Bigger

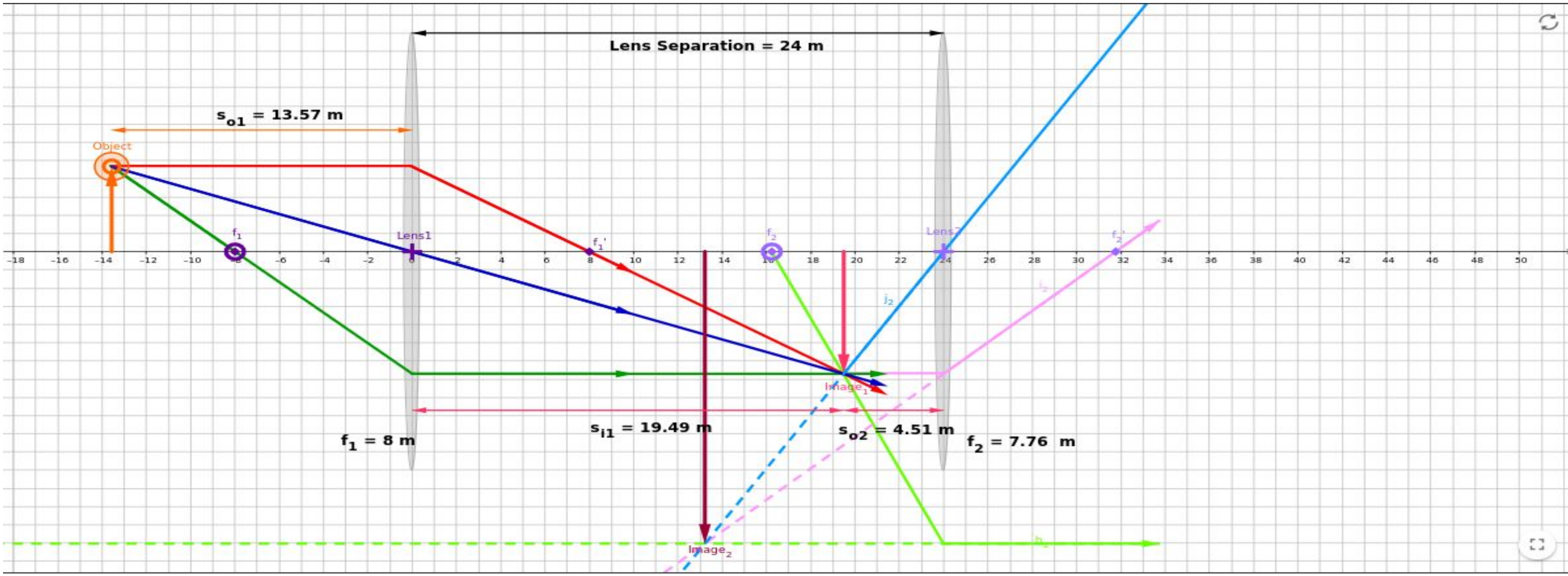
C) Is unchanged

Example of double-lens system with virtual image

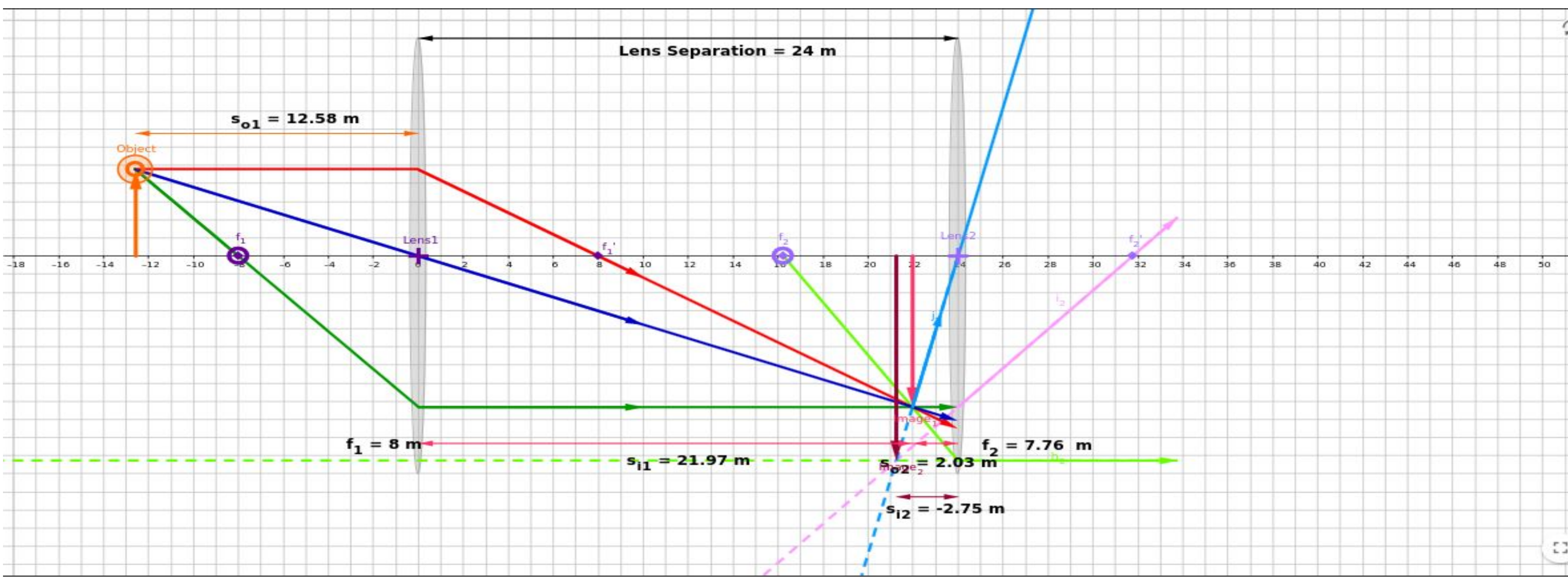


Given: h_1=20; $|f_1|$ =11; o_1=19; f_2=10, lenses 40 cm distant.
find final image by both ray tracing and calculation: Lens1: 1/19+1/i=1/11=>i=26.125 cm
O_2=40-26.125=13.875cm, so 1/13.875+1/i_2=1/10=>i_2=35.8 cm
$m_{tot}=m_1m_2$=>m_{tot}=(-26.125/19.)(-35.8/13.875)=3.55, so final image is 3.55*20=67 cm tall



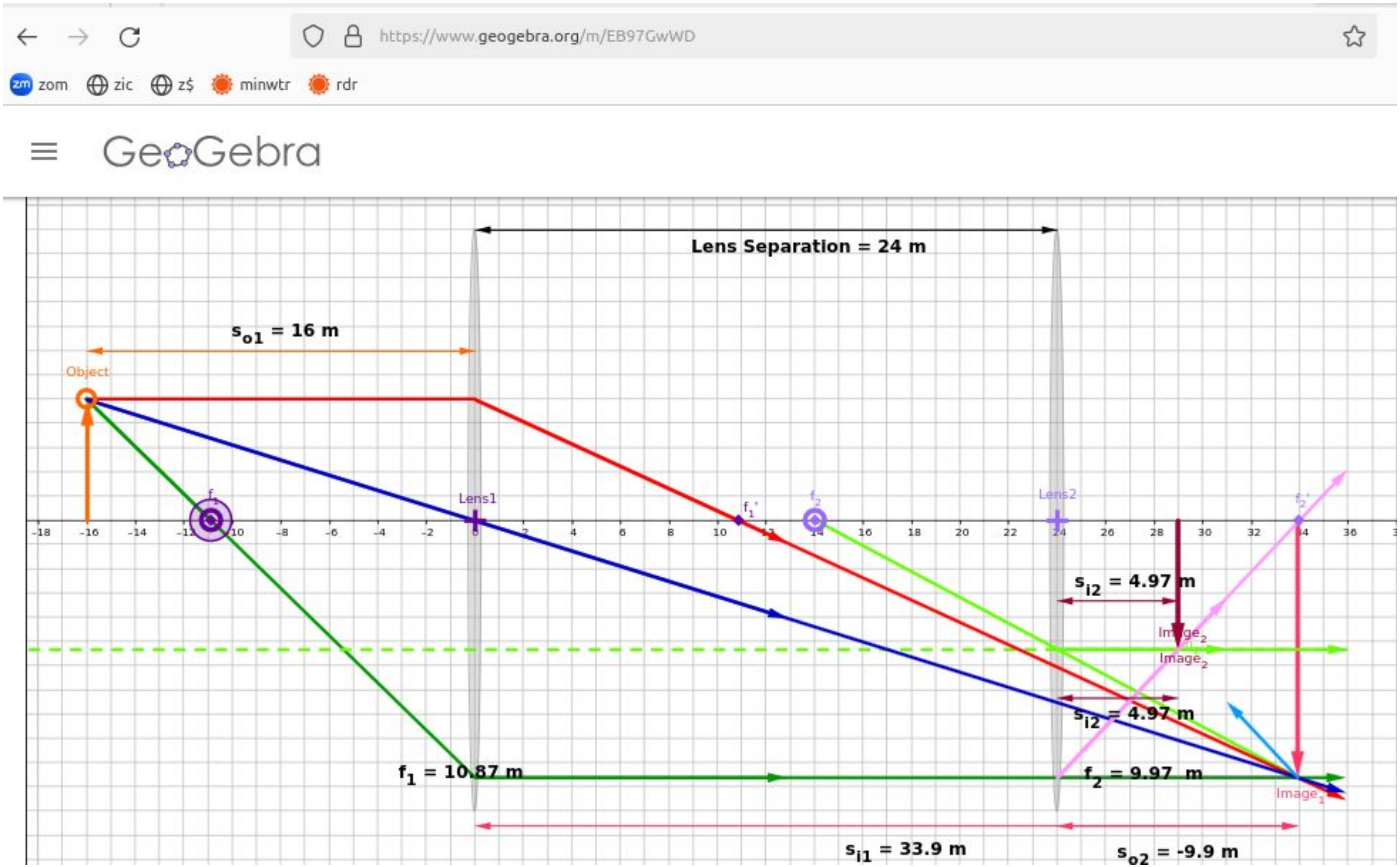


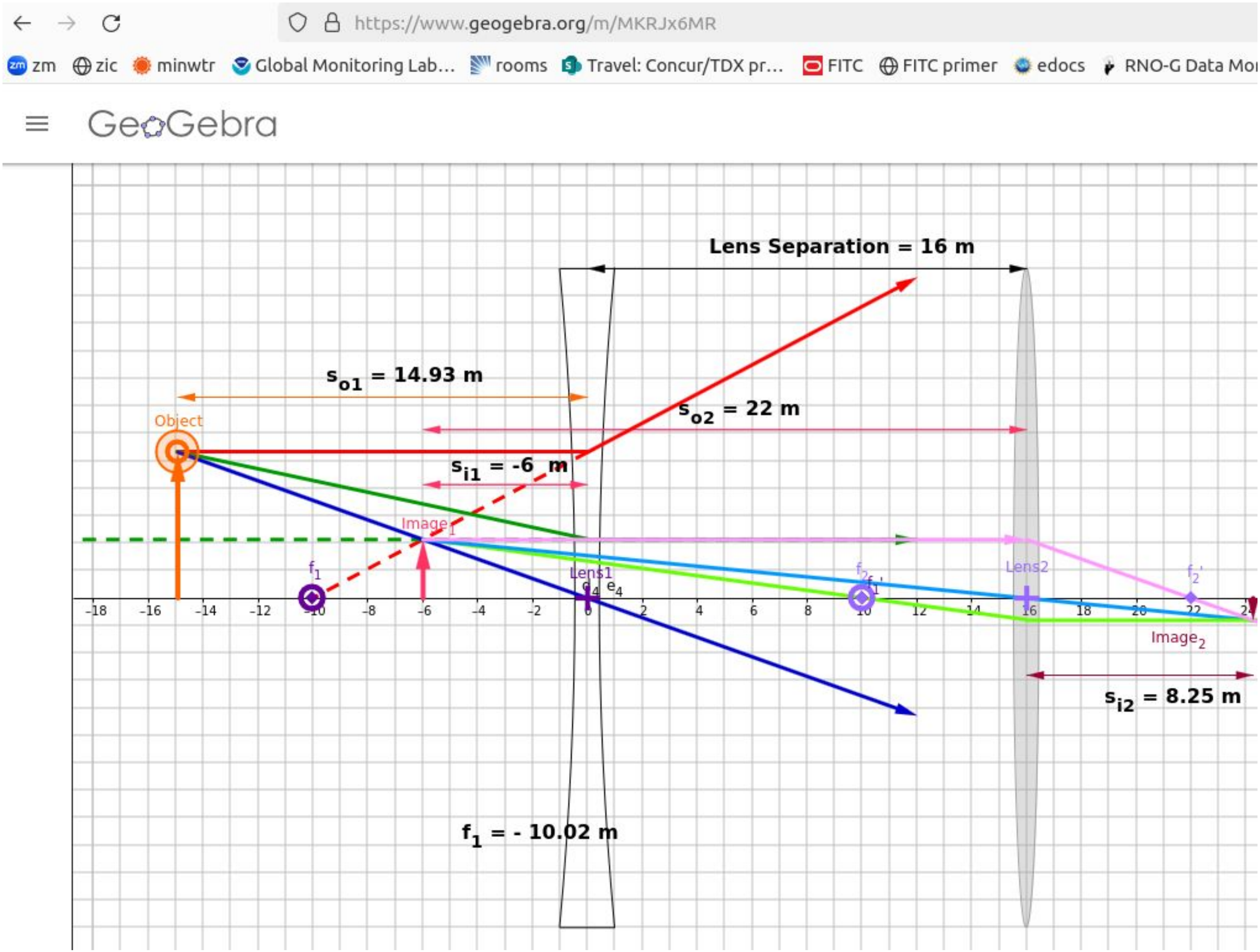
Lens Separation = 24 m
s_{o1} = 13.57 m
Object
Lens1
Lens2
s_{i1} = 19.49 m
s_{o2} = 4.51 m
f_1 = 8 m
f_2 = 7.76 m
Image$_1$
Image$_2$



Lens Separation = 24 m
s_{o1} = 12.58 m
Object
Lens1
Lens2
f_1 = 8 m
f_2 = 7.76 m
s_{i1} = 21.97 m
s_{o2} = 2.03 m
s_{i2} = -2.75 m

N.B. в этом моделировании 1) кажется, что o1 «проходит сквозь» вторую линзу, и 2) вторая линза использует отрицательное расстояние до объекта в формуле тонкой линзы. Возможное объяснение: изображение на самом деле создается волнами, а лучевая картина здесь нарушается? Вторая концептуальная проблема: почему i2 не становится o3 для L1?




https://www.geogebra.org/m/MKRJx6MR
zm
zic
minwtr
Global Monitoring Lab...
rooms
Travel: Concur/TDX pr...
FITC
FITC primer
edocs
RNO-G Data Mo
GeoGebra
Lens Separation = 16 m
s_{o1} = 14.93 m
Object
s_{o2} = 22 m
s_{i1} = -6 m
$Image_1$
f_1
Lens1
e_4
f_2
f_1'
Lens2
f_2'
$Image_2$
s_{i2} = 8.25 m
f_1 = - 10.02 m
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
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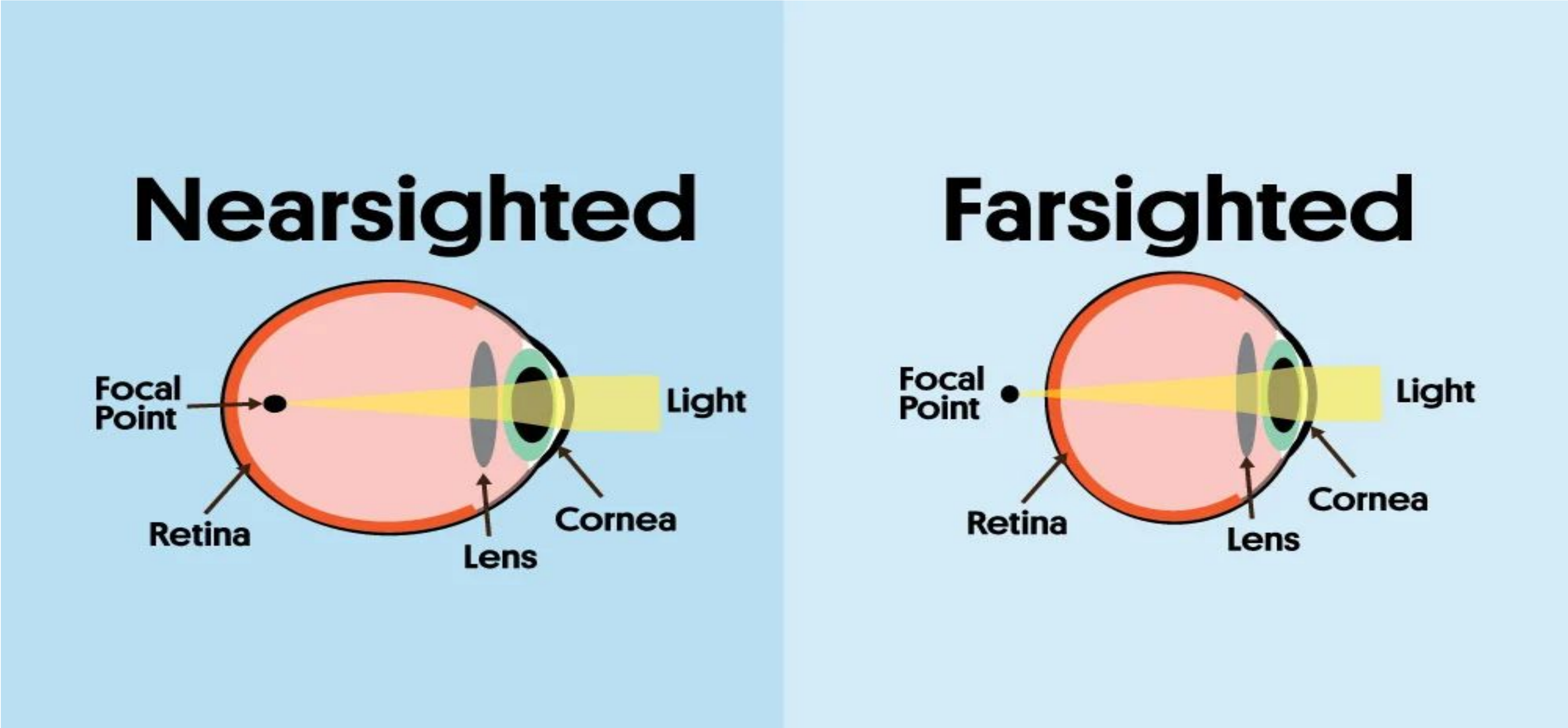
16
18
20
22
24



Glasses for nearsighted/farsighted people are:

A) converging/diverging lenses
B) converging/converging lenses
C) diverging/converging lenses
D) diverging/diverging lenses

A 20 cm high object is 50 cm from L_1 (f=+30 cm) and 185 cm from L_2(f=+20 cm). How big is the final image?

A) 20 cm

B) 6 cm

C) 12 cm

D) 15 cm

E) NOTA

If the object moves slightly closer to the first lens, which is true of the magnification magnitudes?

A) M_1 increases, M_2 increases

B) M_1 increases, M_2 decreases

C) M_1 decreases, M_2 increases

D) M_1 decreases, M_2 decreases

If object is 1 cm high, given $|f_1|$=4 cm, o=6 cm, $|f_2|$=8 cm, d(conv. lens 1$\rightarrow$conv. lens 2)=18 cm, find size of i_2

A) 12 cm

B) 8 cm

C) 6 cm

D) 24 cm

E) NOTA

X stands in front of a mirror. Draw the rays coming from her head which leads to the image of her head in the mirror.

A 4 cm tall object is located 12 cm from a concave mirror having radius of curvature 8 cm. How large is the final image?

A) 4 cm

B) 2 cm

C) 8 cm

D) 1 cm

E) NOTA

As the ends of the mirror are bent outwards, the image gets

A) Larger

B) Smaller

C) Is unchanged

A 4 cm tall object is located 12 cm from a convex mirror having radius of curvature 8 cm. How large is the final image?

A) 4 cm

B) 2 cm

C) 8 cm

D) 1 cm

E) NOTA

An object is 8 cm in front of an R=12 cm concave mirror. As the object moves from 8 cm away to 4 cm away, the image changes from:

A) Real → virtual

B) Inverted → upright

C) Virtual → real

D) Upright → inverted

E) Two of the above

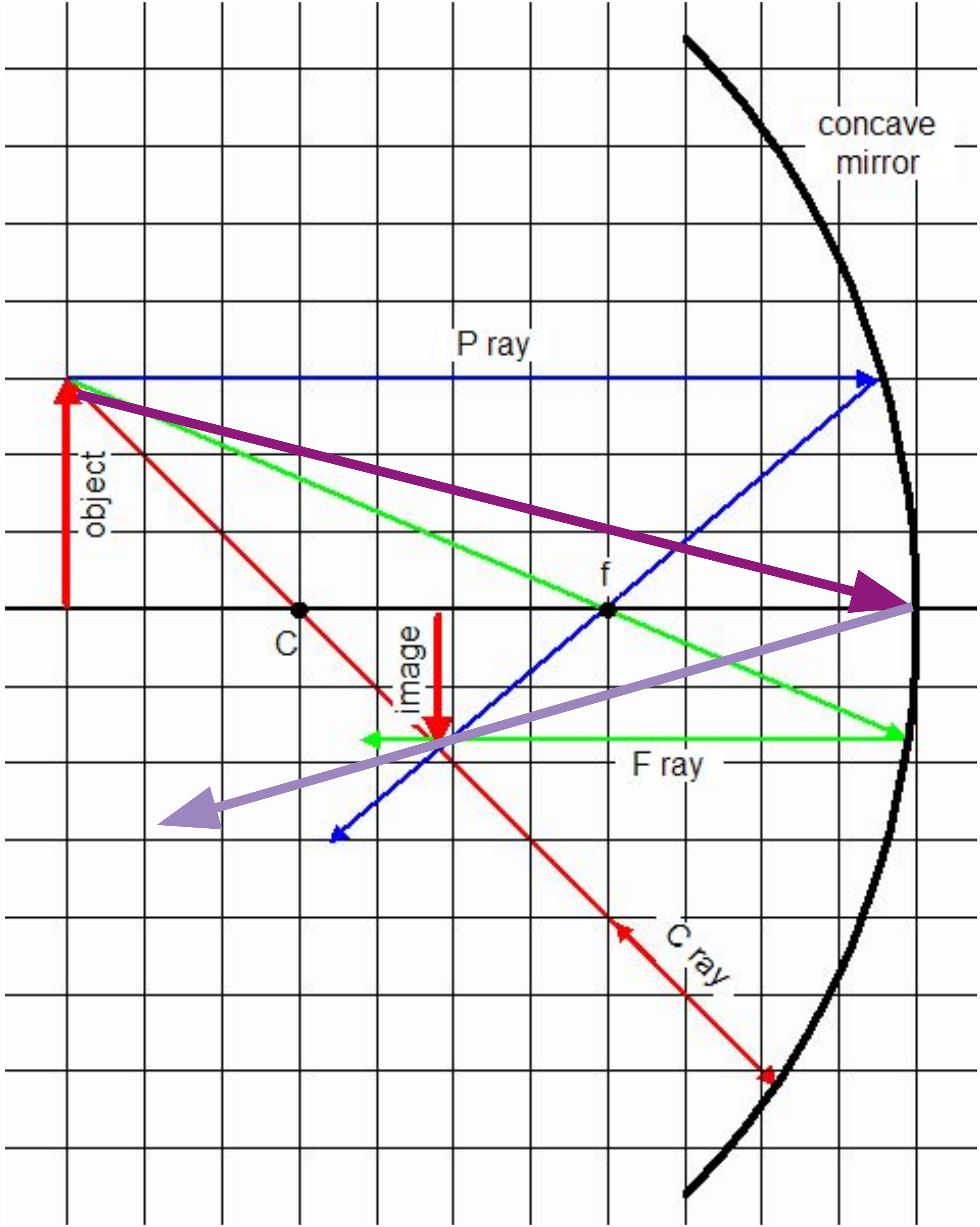
A 4 cm object is 18 cm to the right of an f=+8 cm lens and 12 cm to the left of an 8 cm radius of curvature mirror. The ratio of the image heights ($i_{\text{lens only}}/i_{\text{lens + mirror}}$) is:

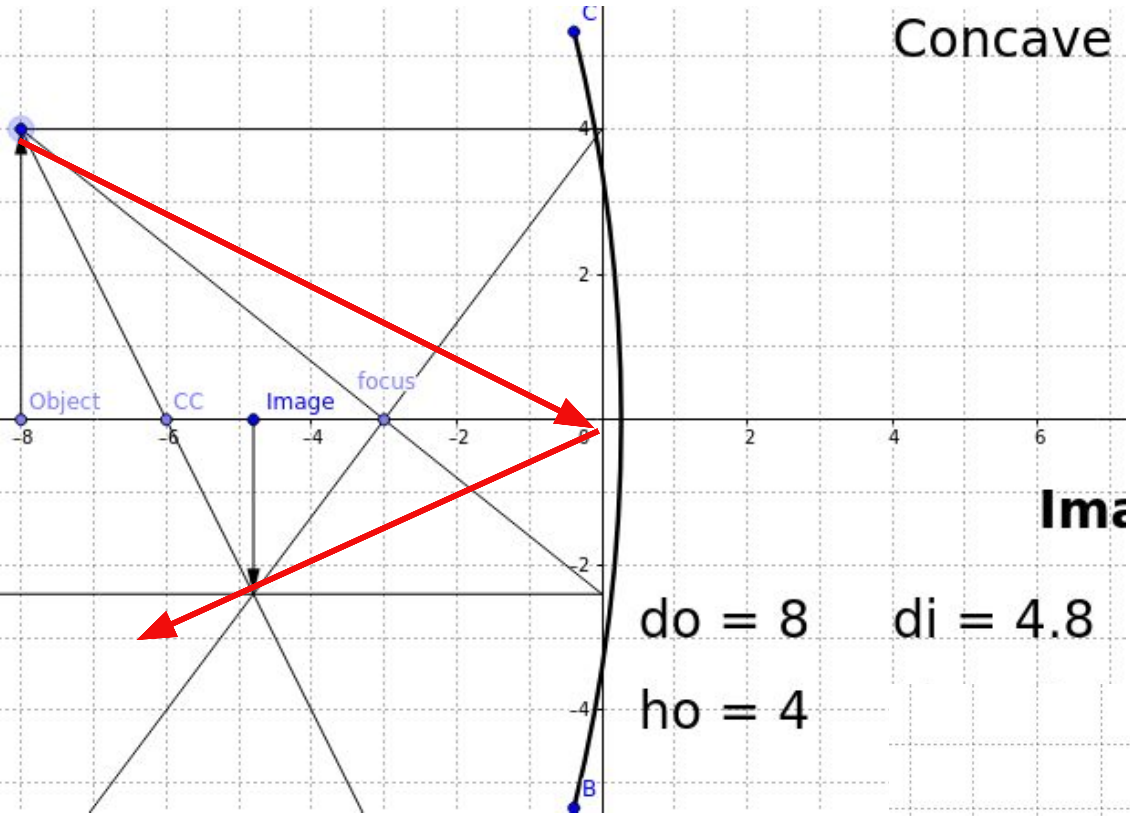
A) >1

B) =1

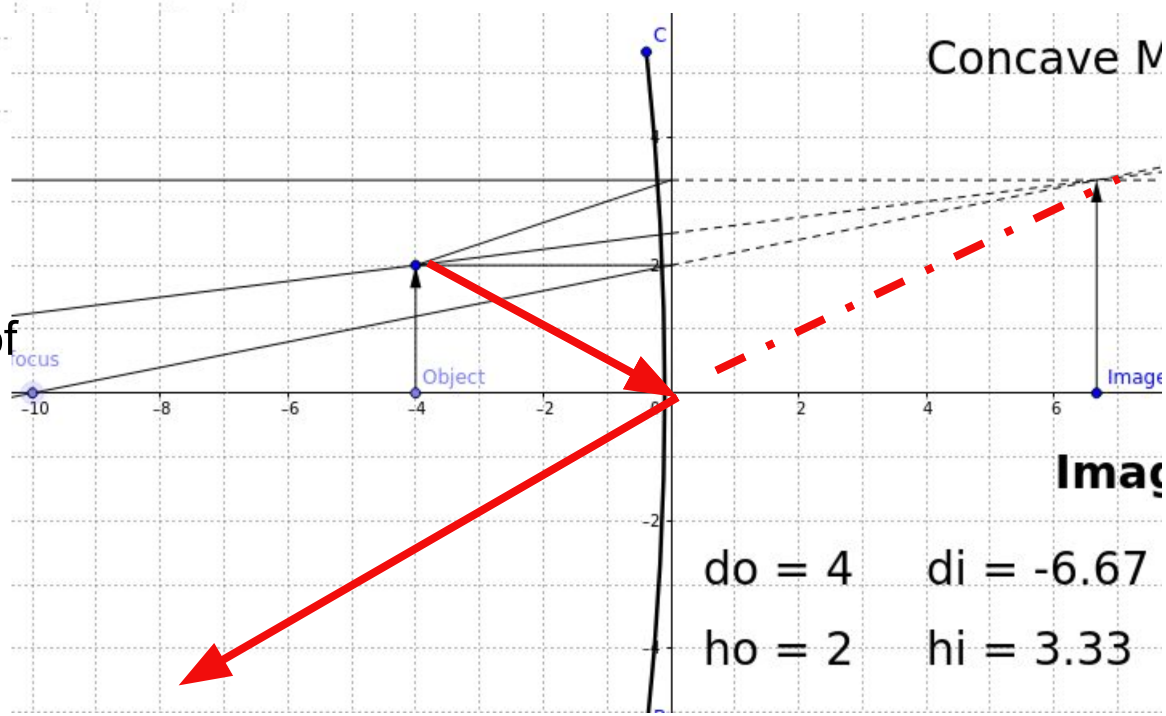
C) <1

D) 0


concave mirror
P ray
object
f
C
image
F ray
C ray

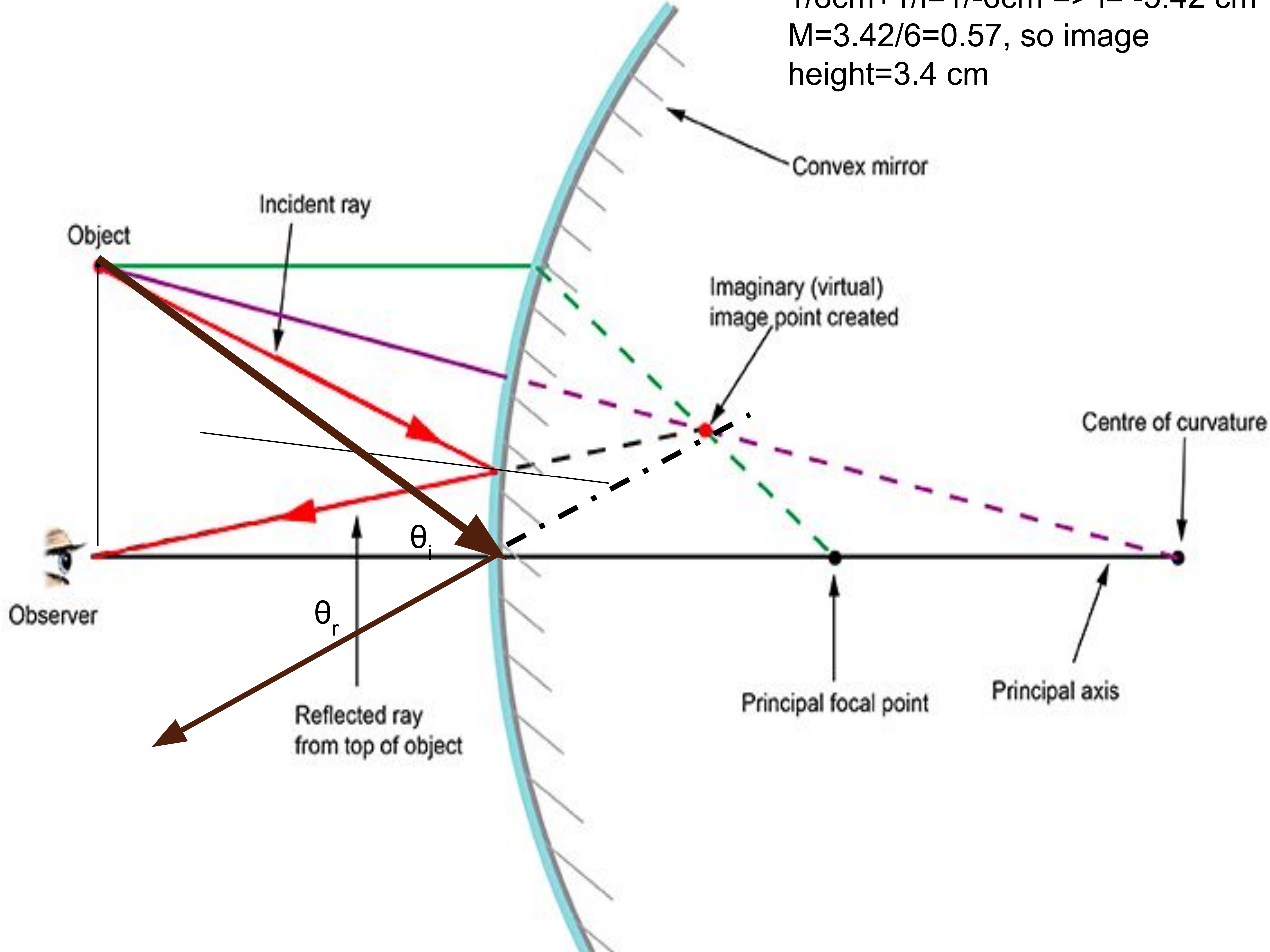


Top: |f|=3; 1/i+1/8=1/3; m=-i/o,
Solve for i=4.8, so m=-4.8/8, so height of image=-(4.8/8)*4cm, or 2.4 in magnitude, but negative sign tells us inverted.



Bottom: 1/i+1/4=1/10; m=-i/o,
Solve for i=-6.67, so m=1.67, so height of image=1.67*2cm, or 3.33 in magnitude; positive sign tells us upright.

H_o=6 cm; |f|=6 cm; d_o=o=8 cm
1/8cm+1/i=1/-6cm => i= -3.42 cm
M=3.42/6=0.57, so image height=3.4 cm



Hubble: spherical aberration – periphery too flat by 0.0022 mm

As the ends of the mirror are bent outwards, the image from the lens+mirror system gets

A) Larger

B) Smaller

C) Is unchanged

Atomic Physics:

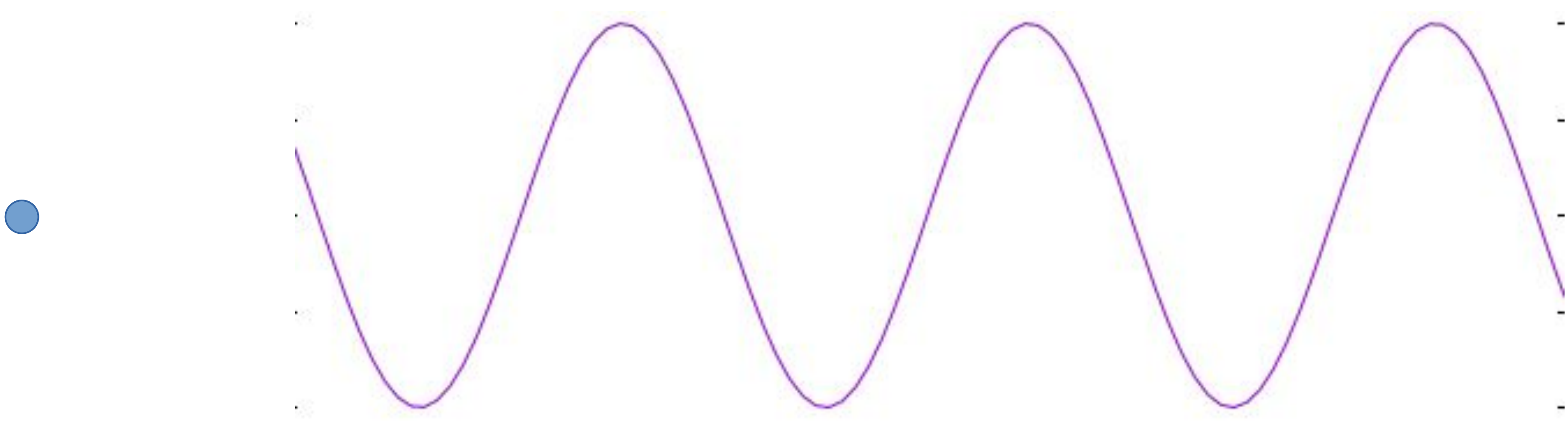
Wave-particle duality:

Newton: `photon'/Huygens: `wave' (1900: "Spectre haunting Europe"). 1) Michelson-Morley

2) Photoelectric puzzle: crank up intensity, but never get a photoelectron (same as in solar cell, or SiPM, or plant leaf) if λ large. But, small λ at low intensity gives P.E. Planck: Light energy delivered in bundles (quanta), each bundle has energy $hc/\lambda=hf_{light}$. So light wave has particle-like properties. DeBroglie: particles behave like light, as well: dimensionally (KE, e.g.): [E]:[p][v], for photon: E=pc, so $p=h/\lambda$. Significance of λ for Bohr model of Hydrogen and resolution of stability of electron orbital. Physical significance vis-a-vis: "Where is electron?" Electron simultaneously occupies entire region defined by one wavelength.... (EPR and reln to Heisenberg Uncertainty).

$$L=nh/2\pi$$

Quantum Mechanics:
- Huygens/Newton: Light is a wave/particle.
- deBroglie: ‘particles’ (well-defined location) also can act like ‘waves’ (spread out).
- More generally, any particle property (position, energy, momentum, spin) is ‘spread out’ until the particle is acted on by another force, particle, etc.



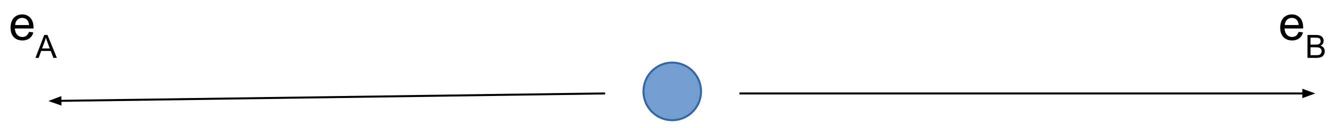
Einstein-Padolsky-Rosen

A particle with no spin decays into two electrons, at t=0, which recoil from each other. If each electron can be either + or – spin, the probability that graduate student A (indpdt of B) measures the e_A with + spin is:

A) 0%

B) 50%

C) 100%



Suppose the graduate students agree that GS A will measure the spin of electron A at midnight, and GS B will measure the spin of electron B at midnight+1 nanosecond. They let the two electrons migrate to opposite ends of the Universe, then GS A measures electron A to be + spin. The probability that GS B subsequently measures electron B to be + spin is now:

A spin-0 X-particle decays into an electron and a positron, which move away from each other at $v=0.5c$. After 3 seconds, how long does it take information from the first e^- to reach the 2nd?

A spinless, stationary particle X decays into a spin ½ electron and a spin ½ positron. Which is true?

A) The probability of measuring the electron spin-up is always ½

B) The probability of measuring the positron in the spin-up state after the electron has been measured in the spin-down state is ½

C) The probability of measuring the positron in the spin-up state after the electron has been measured in the spin-down state is 1

D) NOTA

Find the number of yellow (λ=620 nm) solar photons passing through a 10 cm x 10 cm sheet in 2 seconds, using S_{solar}=1367 W/m^2, the energy per photon $E=hf=hc/\lambda$, and using 1.6×10^{-19} Joules per eV (hc=1240 eV-nm)

A) 45.2

B) 9×10^9

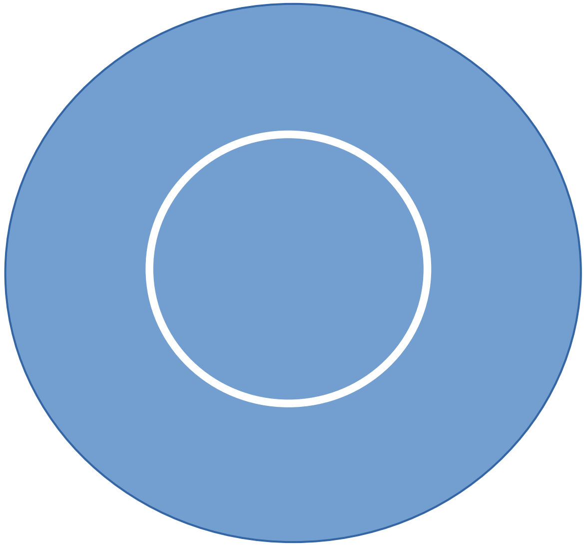
C) 8.54×10^{19}

D) 1.71×10^{20}

E) NOTA

A beam of electrons is shot out of a gun (in a physics classroom [legal at KU!]) with velocity v. Comparing the 'phase' at the two points (as with light), what is the relative intensity at (x_1,t_1) compared to (x_2,t_2). *NB: 'wave' oscillates at velocity of light!*

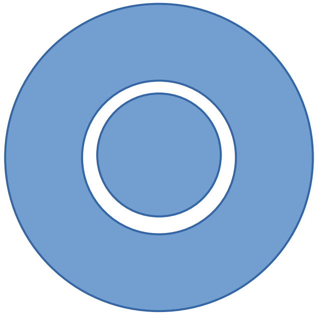
A small circular aperture is cut into an otherwise solid sheet. If light is shone at the sheet, a point directly behind the aperture will be:



A) dark

B) bright

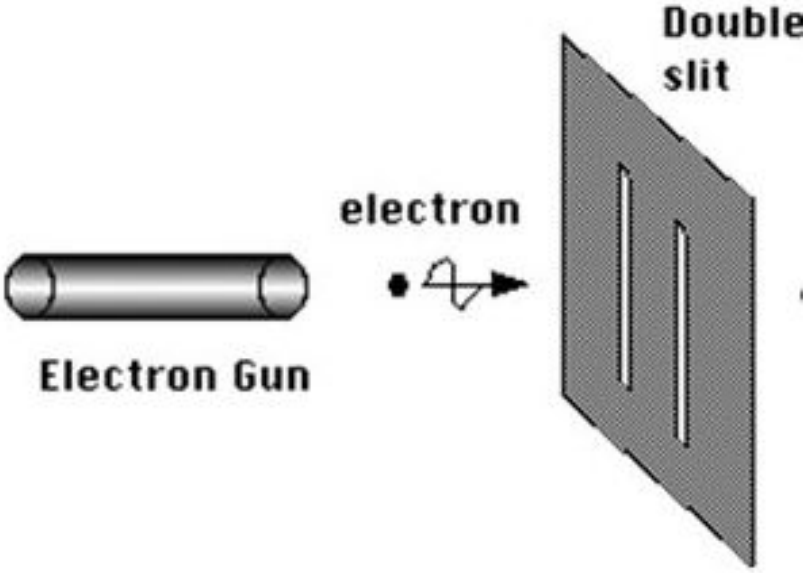
A small circular aperture is cut into an otherwise solid sheet. A beam of slow electrons is shone at the sheet. A point directly behind the aperture is



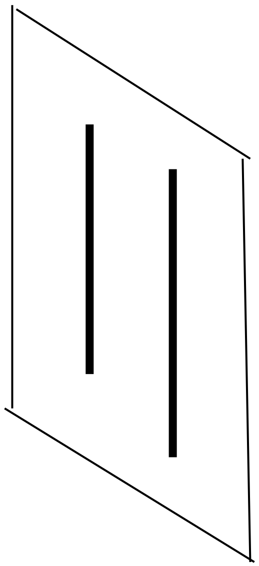
A) dark

B) bright

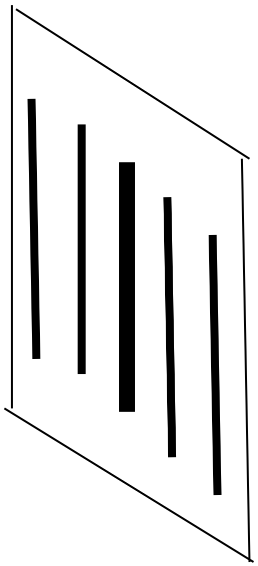
You have a 'gun' that fires high-energy single electrons (such that $\lambda = h/p$ is comparable to the slit separation) at a double-slit apparatus. The 'gun' fires over a range of angles, so you don't know which slit the electrons go through. Assuming the electron gun is very far from the double-slit screen, which pattern of electron 'hits' would you expect to see on the screen? (Assume the slits are infinitely thin, so the the electrons cannot deflect off the walls of the slits themselves)



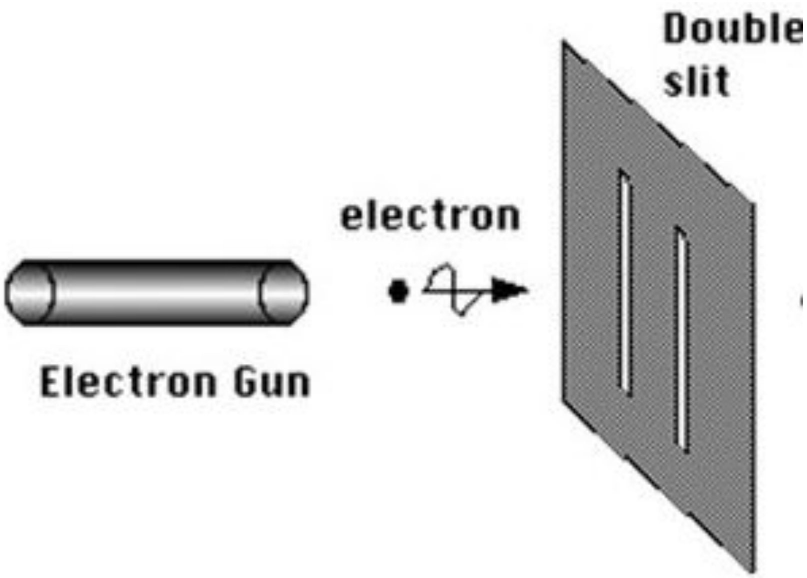
A)

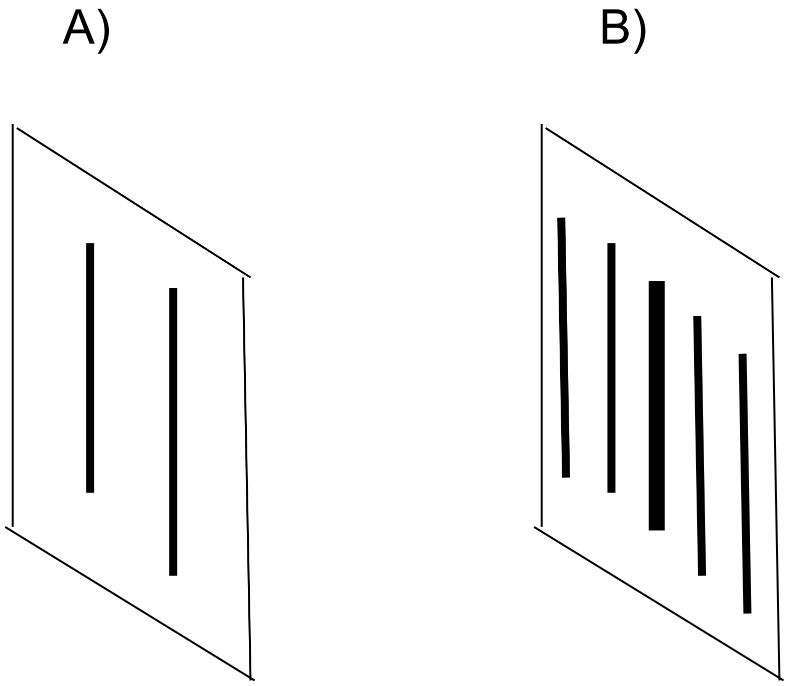


B)



Baffled, you now decide to illuminate the electron before it gets to the slits to 'see' which slit it went through. Which pattern do you observe now?





Moral of the story:
In the first case, the electron exhibits wave characteristics. The single electron ‘wave’ simultaneously goes through both slits. In the second case, you have ‘collapsed the wave function’ and forced the electron to behave as a particle.

A particle having mass 3.315 x10^{-31} kg is shot from a gun with velocity 2 cm/s. What is the wavelength of the *wave* associated with this particle?

A) 1 m

B) 10 cm

C) 1 cm

D) 1 mm

E) NOTA

In the previous problem, the 'frequency' associated with the particle 'wave' is:

A) 2×10^{-24} /s

B) 4×10^{-5}/s

C) 8×10^{-12}/s

D) 3×10^{9} /s

E) NOTA

Does $f\lambda=v$ for this 'particle-wave'?

A) No

B) Yes

Electrons are "fired" at a double-slit apparatus. Which of the following has the effect of reducing the spacing between electron "intensity" maxima on the screen (recall that $m\lambda = d\sin\theta$ is the constructive interference condition for waves in phase at the source)?

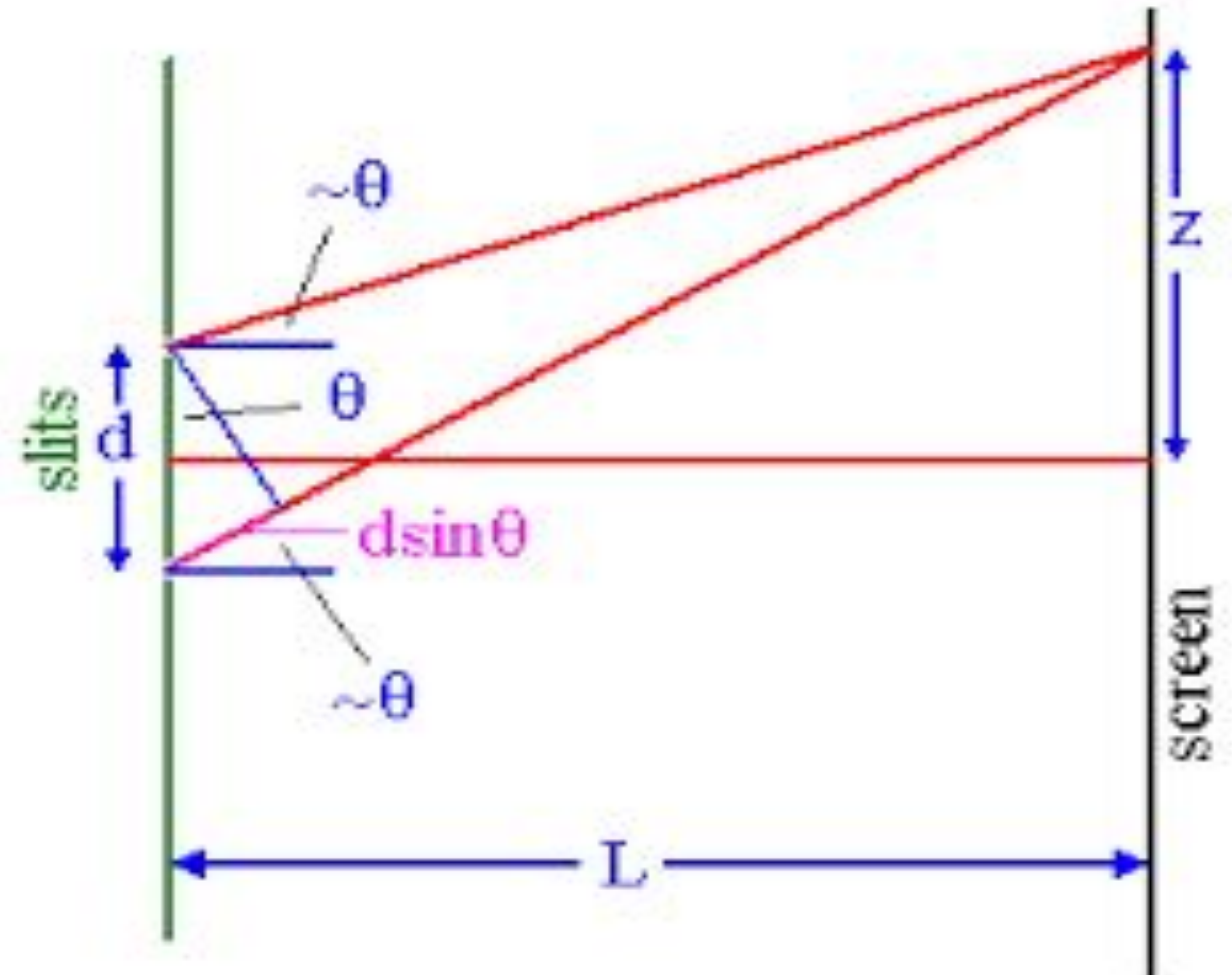
A) Increasing electron velocity

B) Increasing (if possible) electron mass

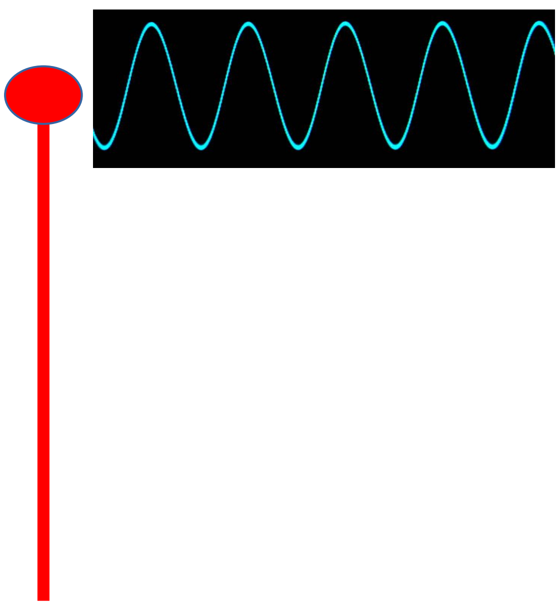
C) Increasing spacing between slits

D) Two of the above

E) All of the above

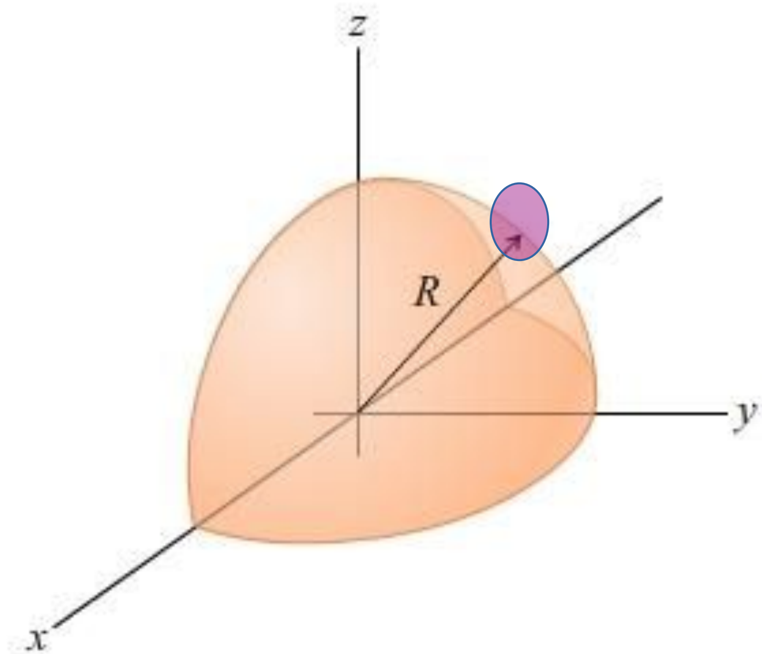


WDZB-FM broadcasts EM waves having λ=1.5 m, with P=40 kW. 1) (review) Determine the energy intensity ([J/s-m^2] at a distance of 1000 meters from the source antenna, assuming the broadcast power is beamed hemispherically; from that value, now determine a) $|E_{rad}|$ using $S=E_{rad}{}^2/240\pi$, and b) the energy passing through a 0.25m^2 surface, over t=8 s. 2) (new) Now we transition to the "photon" picture: From λ, determine f, and, from that, E per photon. Now determine a) the total number of photons intercepted by your surface after 8 seconds, and b) if the surface is a perfect reflector, using the formula for the momentum of each photon, determine the recoil velocity of the surface, if it has a mass of 2 micrograms.



$S=40000/\text{Area}=40000/(2\pi*10^6)=6.37e\text{-}3=E_{rad}{}^2/240\pi$, so E_{rad}=2.19 N/C; Energy thru 0.25 m^2 in 8s=0.0127J
Photon picture: f=3e8/1.5m=200e6 Hz; E_{photon}=hf; h=6.63e-34, so E_{photon}=1.33e-25 J. To get to 0.0127J, we need 0.0127J/1.33e-25J=9.6e22 photons.
Momentum of each photon=E_{photon}/c, so total momentum transferred to 2 microgram surface=(0.0127J/3e8) x 2 (since perfect reflector) = 4.23e-11 kg-m/s=$m_{surface}v_{recoil,surface}$, using $m_{surface}$=2e-6 kg gives v_{recoil}=4.23e-5 m/s

WDZB-FM broadcasts EM waves at a f=1200 MHz, with an output power of 200 W into one-quarter of a full sphere (as shown). At R=60m, the energy intensity [W/m^2], E_{rad} magnitude, and total energy passing through a disk of radius 2m, in a time t=3 seconds, are:



A) 0.22 W/m^2, 4.77 N/C, 0.667 J

B) 0.0044 W/m^2, 4.77 N/C, 0.333

C) 0.055 W/m^2, 4.77 N/C, 0.30 J

D) 0.017 W/m^2, 3.65 N/C, 0.667 J

E) NOTA

The total number of photons passing through the surface, in the same time, is:

A) 8.38×10^{23}

B) 4.1×10^{24}

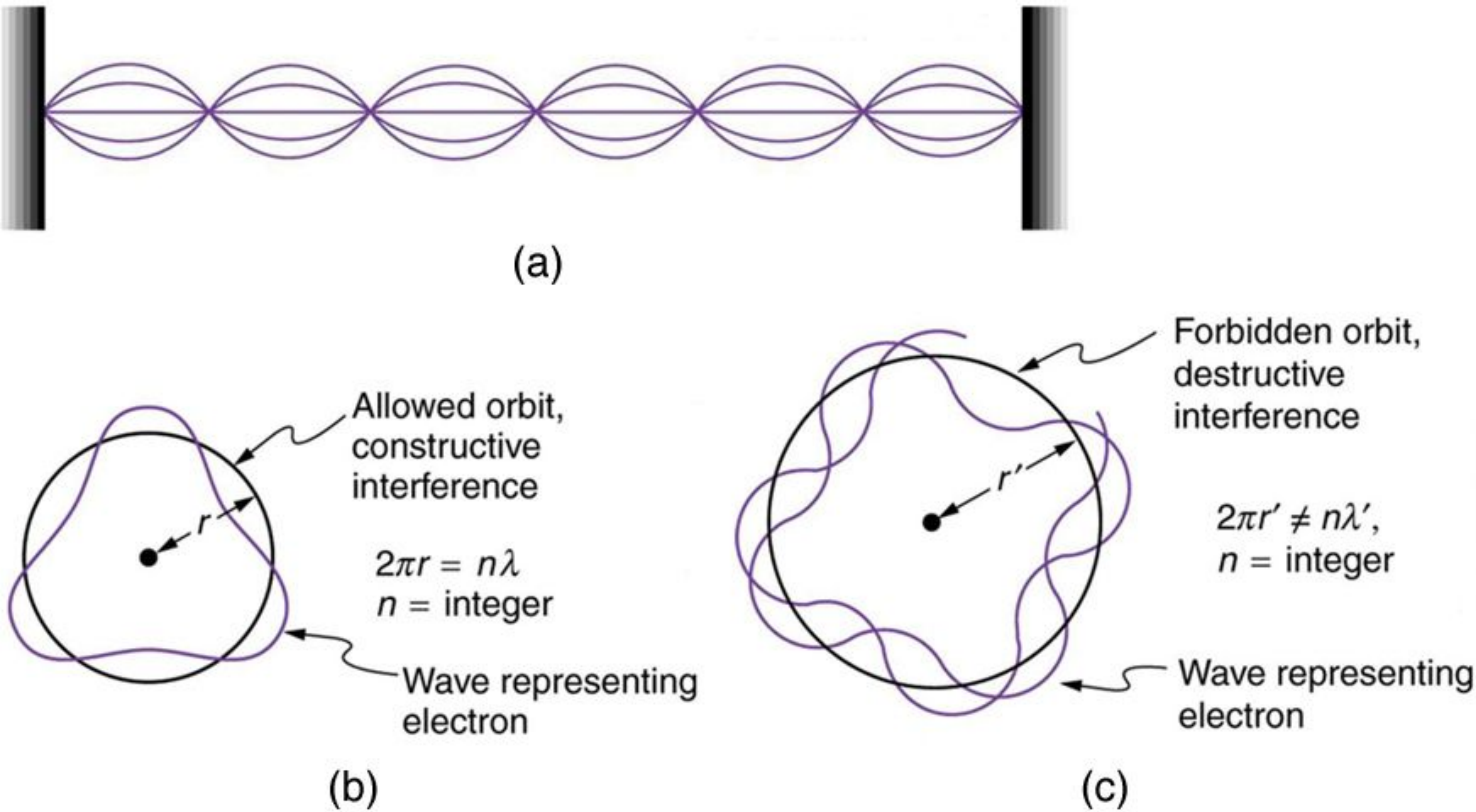
C) 4.1×10^{7}

D) 589.1

E) NOTA

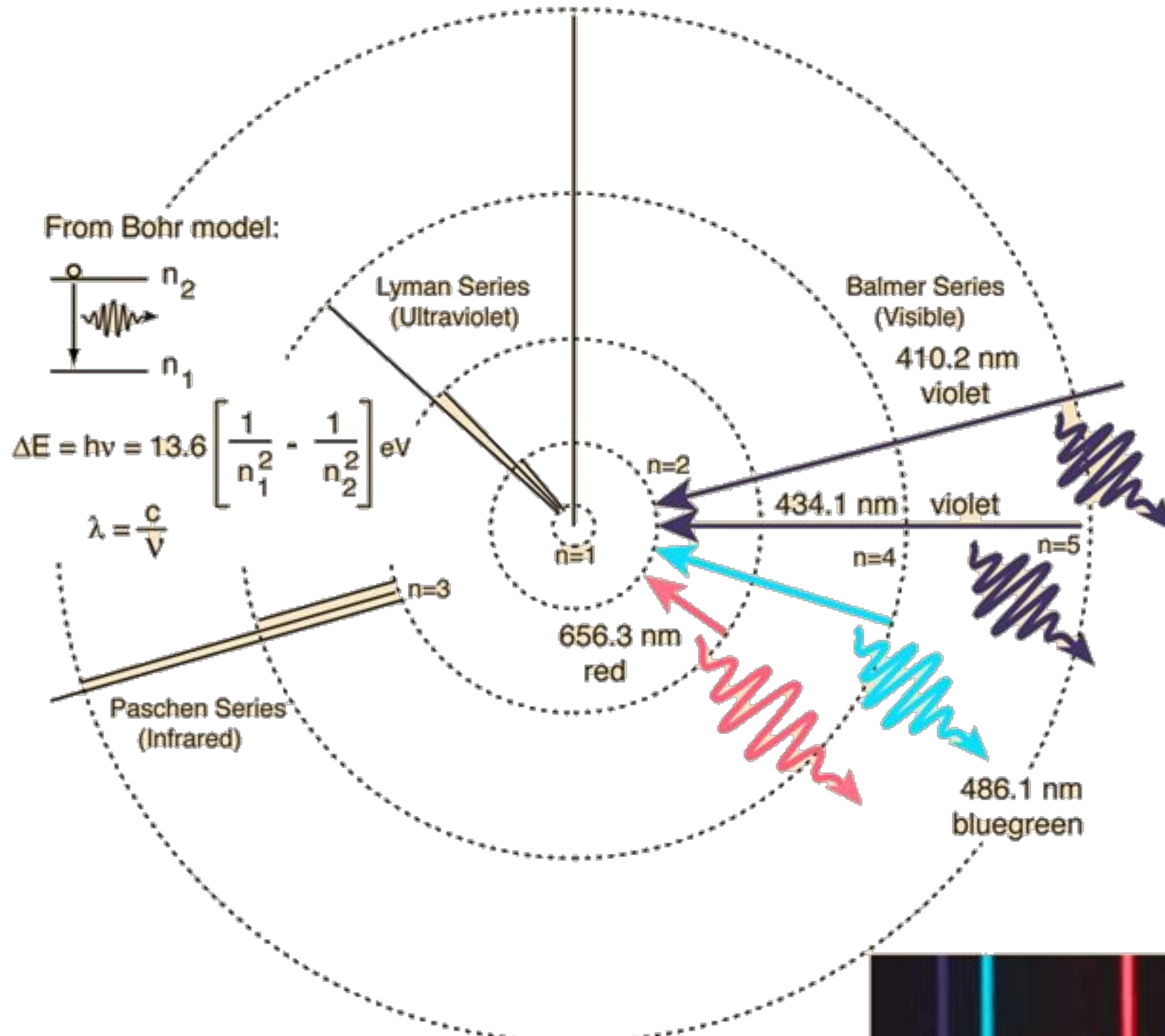
Assuming the disk is a perfect reflector having mass 10 nanograms, the recoil velocity of the disk is:

A) 44.43 m/s
B) 4.443 m/s
C) 0.444 m/s
D) 0.044 m/s
E) NOTA



(a)
Allowed orbit,
constructive
interference
r
2πr = nλ
n = integer
Wave representing
electron
(b)
Forbidden orbit,
destructive
interference
r′
2πr′ ≠ nλ′,
n = integer
Wave representing
electron
(c)

Pictoral summary of Bohr model



The wavelength of light emitted in the n=3→n=2 Hydrogen transition is:

A) 121 nm

B) 656 nm

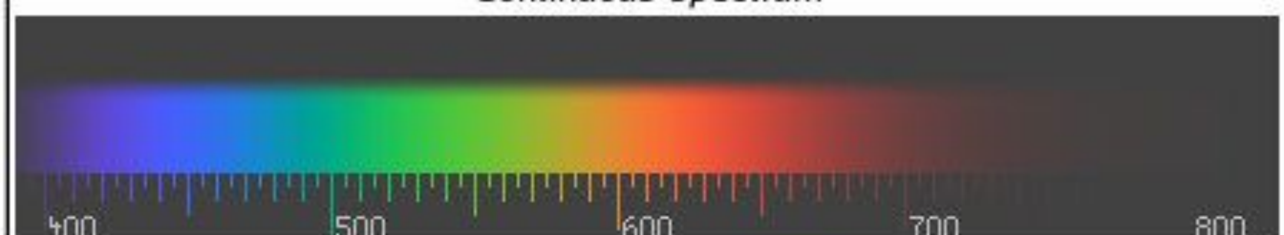
C) 102 nm

D) 456 nm

E) NOTA

color	wavelength interval	frequency interval
red	~ 625-740 nm	~ 480-405 THz
orange	~ 590-625 nm	~ 510-480 THz
yellow	~ 565-590 nm	~ 530-510 THz
green	~ 500-565 nm	~ 600-530 THz
cyan	~ 485-500 nm	~ 620-600 THz
blue	~ 440-485 nm	~ 680-620 THz
violet	~ 380-440 nm	~ 790-680 THz

Continuous spectrum



Designed for monitors with gamma 1.5.

Virial Theorem: For a particle stuck in an attractive, circular orbit:

$$kq^2/r^2=mv^2/r \Rightarrow$$

$$kq^2/r=mv^2 \Rightarrow (V=kq/r):$$

$$qV=mv^2$$

$$|PE|=2KE$$

A particle with $m=1.657\text{x } 10^{-26}$ kg and $v=4\text{x}10^{4}$ m/s moves in a circular orbit. The smallest radius r such that the orbit is 'stable' is:

A) 0.01 cm

B) $1.59 \text{ x } 10^{-13}$ m

C) $2.4 \text{ x } 10^{-31}$ m

D) $1.6 \text{ x } 10^{-19}$ m

E) NOTA

If the particle's mass were increased (but velocity unchanged), then the smallest stable orbital radius, relative to the previous case, would be:

A) larger

B) smaller

C) unchanged

Light of wavelength 248 nm strikes a metal plate with W_o=3 eV. The KE with which the ejected e^- strikes a metal bar held at V=+8V is:

A) 5 eV

B) 3 eV

C) 10 eV

D) 13 eV

E) NOTA

In the previous problem, which would increase the KE of the e^- striking the bar?

A) W_o increased

B) Increasing λ

C) Increasing V_o

D) Two of the above

E) NOTA

From the velocity solved for (and the implied acceleration) in the previous problem, what is E_{rad} at 1 meter?

From E_{rad} in the previous problem, what is the energy intercepted by a 1 cm x 1 cm square at 1 m?

From the solution to the previous problem, what is the total power radiated by the electron?

From the output power in the previous problem, what is the lifetime of an electron orbiting Hydrogen?

Alternately, calculate the total power directly from the Larmor formula for a non-relativistic charge accelerating at a: $P=(2/3)kq^2a^2/c^3$

In this CAP, we'll work our way backwards from an "observation" of a spectral line due to electron transitions from the n=2->n=1 state to deduce the nuclear charge of the atoms, whose transitions are being observed, using the "virial theorem", combined with several equations from 114 & 115. Here goes:

In your capacity as the Astronomer Extraordinaire of the Royal Astronomical Association of Kansas, and desperate for a sensational observation to save your organization from the chopping block of fiscal responsibility (" "), you have devoted yourself to searching in the skies for something/anything to grab headlines. One night, you observe, in a scan of the sky, a spectral line having wavelength X nanometers (X<200 nm). You realize that you are observing a transition from the 2S state to the 1S state of electrons in a possibly unobserved atom; and set yourself to the task of identifying the Z-value of that atom, as follows:

a) You first convert the observed wavelength into an energy, in electron Volts of the photon you've observed.

b) Now you use the fact that, since the energy of your observed photon is 3/4 the magnitude of the energy of the "ground state" of the electron, you determine the magnitude of the ground state energy.

c) Now you invoke the virial theorem, which tells you that the kinetic energy of the electron is the same as the ground state energy magnitude you just determined, which allows you, knowing the velocity of the electron in the ground state.

d) knowing the velocity, you use Bohr's principle that the ground-state angular momentum is equal to nh, with n=1 in the ground state, to determine the distance between the electron and the nucleus r.

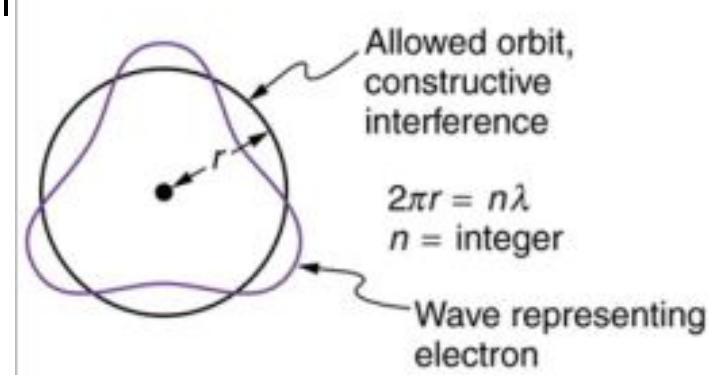
e) Finally, using the virial theorem once more, and knowing that the magnitude of the potential energy is twice the magnitude of the kinetic energy, you determine the charge of the nucleus.

Pick 3S energy level for Beryllium (Z=4): need: $mv=h/\lambda$, $2\pi r=3\lambda=3(h/mv)$ and $kq(4q)/r^2=mv^2/r$
Solve for $r=3h/(2\pi mv)$; rewrite $4kq^2/r=mv^2$ and now plug $r=3h/(2\pi mv)$ and solve for $Mv^2=(4kq^2)*(2\pi mv)/3h$; m cancels, so $v=(4kq^2)(2\pi)/3h$; q=1.6e-19 C, h=6.634e-34 J-s, k=9e9, so $v=2.91\times10^6$ m/s. This is about 1% of the speed of light, $r=3h/(2\pi mv)$=1.19e-10 m

Can now calculate KE ($\frac{1}{2}mv^2$), with $m=9.11\times10^{-31}$ kg for electron (NOT proton!) and PE (kq_e*4q_p/r);
Note that PE is negative since $q_e<0$ and $4p_p>0$, find:
PE(e-)=-7.74e-18 J (using 1eV=1.6e-19J, this is equal to -47.62 eV)
KE(e-)= 3.87e-18J or 23.81 eV; total E=PE+KE=-23.81 eV
Note that Virial Theorem checks out! |PE|=2KE

Now consider transitions – we'll take n=3 state to n=1 state. We know that the energy levels go as $E_n=E_{n=1}/n^2$; here we have -23.81 eV=$E_{n=1}/9$, so $E_{n=1}$=-214.29 eV. ΔE magnitude=190.48 eV. What is the wavelength of this photon transition? $hc/\lambda=E_\gamma$=190.48 eV; hc=1240 nm-eV, so λ=6.51 nm (ultra-violet)

Note that for hydrogen, $E_{n=1}$=-13.6 eV. If we've increased the nuclear charge by a factor of 4, why is the n=1 energy so much larger (in magnitude) than that factor of 4? Reason is that the electron is pulled closer to the nucleus, so i ger magnitude of (negative) PE.



Which of the following are the equations needed to solve for r, v, and E of an electron (charge=q) in the 2nd energy level of Helium

A) $m_e v^2/r = kq^2/r^2$; $2\pi r = \lambda$; $mv = h/\lambda$;

B) $m_e v^2/r = k(2q^2)/r^2$; $2\pi r = 2\lambda$; $mv = h/\lambda$;

C) $m_e v^2/r = k(4q^2)/r^2$; $2\pi r = \lambda$; $mv = h/\lambda$;

D) NOTA

An electron in the n=2 level of Hydrogen absorbs a photon of wavelength 200 nm. Determine the electron's KE after ejection from the Hydrogen, using $E_n = -13.6\ \text{eV}/n^2$ and $E_\gamma = hc/\lambda$, with hc=1240 nm-eV

A) 6.044 eV
B) 3.4 eV
C) 13.6 eV
D) 2.8 eV
E) NOTA

If the same photon were incident on an electron in the 2S state of Helium, the KE of the electron would be

A) Smaller

B) Higher

C) The same

The wavelength of a photon emitted in an n=3 → n=2 transition in Hydrogen is:

A) 82 nm

B) 164 nm

C) 328 nm

D) 656 nm

E) NOTA

You are told that the total energy (KE+PE) of an electron in the 3S level of Helium is -6.04 eV. Given that, the potential energy of the electron in the 1S level is

A) -54.4 eV

B) -108.8 eV

C) -27.2 eV

D) 54.4 eV

E) NOTA

Given that the ground state energy of Hydrogen has E_{tot}=-13.6 eV. Using the standard E_n=-13.6 eV*Z^2/n^2 , the n=2 potential energy of Lithium is:

A) -13.6 eV

B) -27.2 eV

C) -54.4 eV

D) -61.2 eV

E) NOTA

Given that $KE=p^2/2m$; and $p=h/\lambda$, comparing the n=1S state of Lithium to the n=2S state implies that the radius of the n=1 state is

A) The same
B) Twice as large
C) Twice as small
D) Four times as small
E) NOTA

An electron in hydrogen orbits the proton at $r=0.529 \times 10^{-10}$ m. Using the fact that $E_n=-13.6\text{eV}/n^2$, what is it's velocity?

A) 3×10^8 m/s

B) 2.19×10^8 m/s

C) 2.19×10^6 m/s

D) 1.4×10^4 m/s

E) NOTA

An electron in the n=6 level of Helium absorbs a photon of wavelength 100 nm. Determine the electron's KE after ejection from the Helium, after it accelerates through a voltage of -2 V

A)

Setting centripetal force (mv^2/r) equal to the Coulomb (electrostatic) force between two charges, and realizing that PE=q(ΔV), you can derive that the PE of a 1s electron is related to the KE of that electron via:

A) PE=KE

B) PE=-KE

C) PE=-2KE

D) 2PE=KE

E) NOTA

A 1s electron ($m=9.11 \times 10^{-31}$ kg, $q=1.6 \times 10^{-19}$ C) in hydrogen orbits the proton at $r=0.529 \times 10^{-10}$ m, with a velocity of 2.19×10^{6} m/s. What is it's KE and PE, respectively? (recall that $\Delta PE=q\Delta V$ and 1.6×10^{-19} J/eV)

A) 13.6 eV, 13.6 eV

B) 13.6 eV, -27.2 eV

C) 27.2 eV, -27.2 eV

D) 27.2 eV, 13.6 eV

E) NOTA

The ratio of velocity of an electron in the 3s orbital, compared to the 1s orbital is:

A) 1

B) 1/3

C) 1/9

D) 3

E) NOTA

In going from Hydrogen to Helium, the 1s electron has:

A) Higher velocity

B) Higher PE

C) Higher KE

D) Smaller radius

E) Two of the above

Given that the mass of Venus is about the same as the mass of Earth, and based on the similarity b/w gravitational and electrical systems, you can conclude that:

A) $PE_{Venus} < PE_{Earth}$

B) $KE_{Venus} > KE_{Earth}$

C) $E_{tot,Venus} < E_{tot,Earth}$

D) Two of the above are true

E) All of the above are true

Which of the following have the effect of increasing the energy of a photon emitted in the n=2→n=1 transition in Hydrogen?

A) Increasing the electron mass

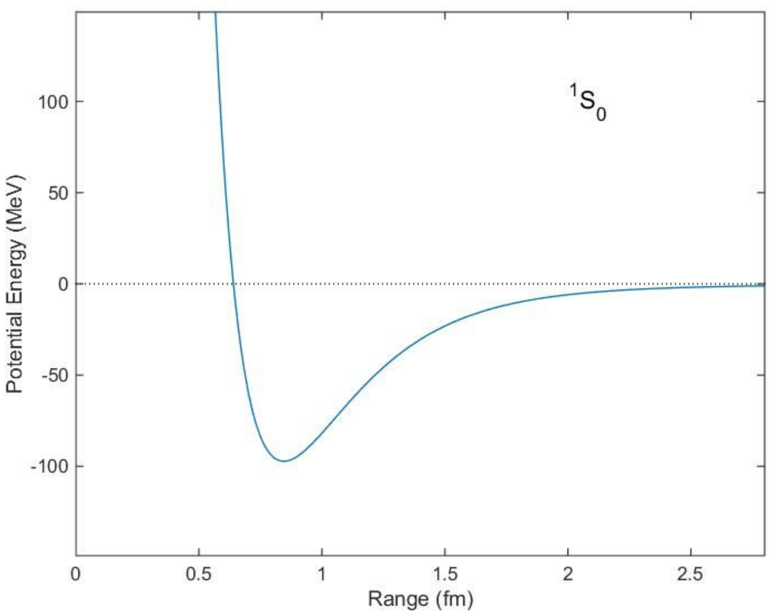
B) Increasing the proton mass

C) Increasing the electron charge

D) Increasing the proton charge

E) Two (or more) of the above

Nuclear Physics:
System moving from high PE to low PE releases energy: Einstein-KE is frame-dependent (consider two putty pieces colliding wrt 'fixed' observer vs. observer on a train.) Fix it by stating that some small part of energy is equal to mass: Particles with smaller PE also have smaller mass!



Suppose two masses start at rest and fall into a 'well'. Phsx114: KE (0) + PE (0)=heat (+) + PE(-)

E(total)=m(total)c^2 = m_0c^2 + PE + KE;
m_0c^2='rest-mass energy' of isolated particle

Two puzzles: nuclei are stable despite proton-proton repulsion, and free neutron decays in 10 minutes, while neutron inside nucleus is stable.

Significance of equivalence of mass and energy: MASS changes when an object is in a potential field!

E(total)=rest-mass energy + PE + KE=m_0c^2

E.g., deuteron, at infty, starting/ending at rest:

$m_{p,0}c^2 + m_{n,0}c^2 + PE_i + KE_i = \boldsymbol{m_{p,in\ nucleus}c^2 + m_{n,in\ nucleus}c^2 + PE_{n,p} + heat}$ $\boldsymbol{m_{pn}}$ + $heat_{Ext}$;

$PE_i=KE_i=KE_f=0$; i.e. $\Delta PE_f=\Delta(mc^2)$

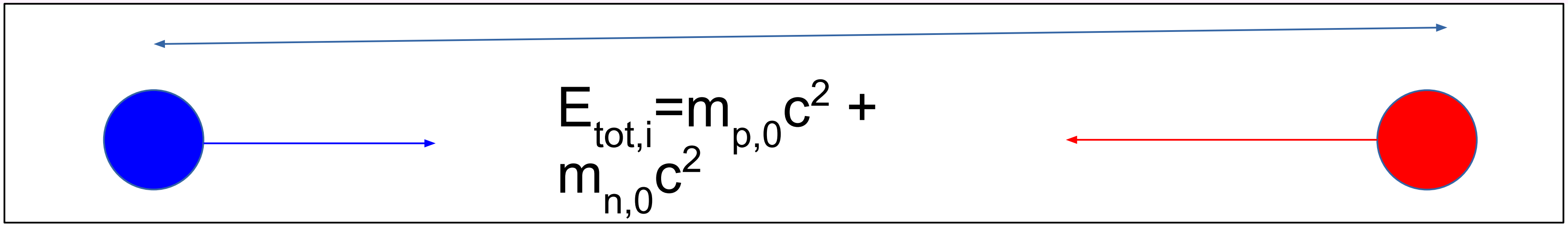
Alternately, can consider from the standpoint of starting with two particles, very far apart:

$m_p+m_n=\boldsymbol{m_{pn}}$+heat; the heat produced is equivalently the depth of the potential energy well, as well as the amount of heat produced in the interaction.

Caution 1: the pn-potential is more than just strong force; caution 2: $m_{deuteron}$ is not equal to $m_{diatomic\ hydrogen}$

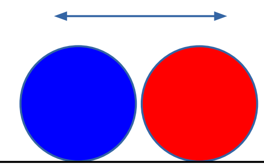
The more negative the PE: 1) the more tightly bound the nucleus, and 2) the smaller the mass per nucleon

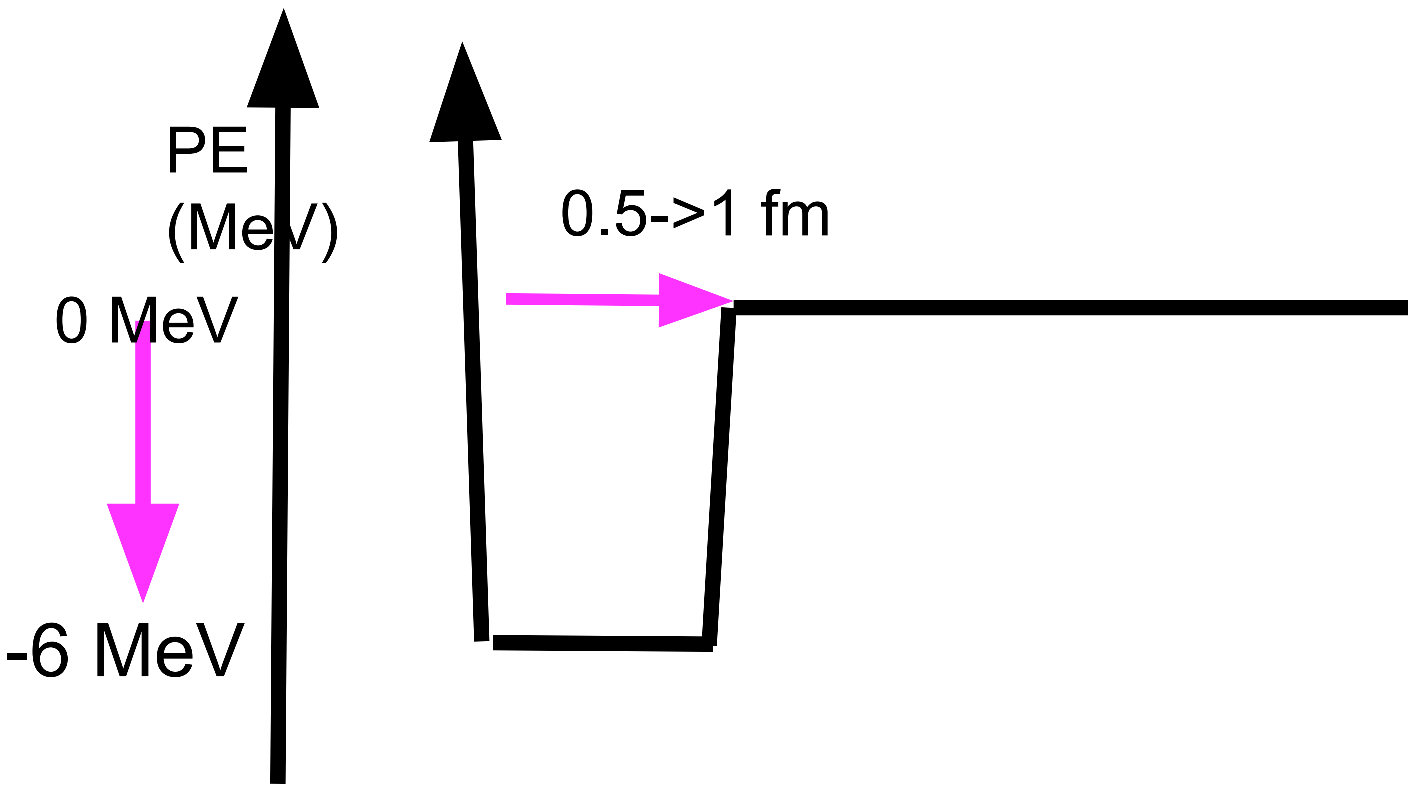
Step-by-step formation of a deuteron (pn)



$E_{tot,i}=m_{p,0}c^2 + m_{n,0}c^2$

$E_{tot,f}=m_{pn}c^2$ + heat; $m_{pn}c^2=m_{p,0}c^2 + m_{n,0}c^2 + PE(p,n)$





Given the PE "well" shown, and using m_{proton} =938 MeV/c^2, $m_{neutron}$ =939 MeV/c^2, with each having a diameter just less than 1 fm, what is the mass of a Helium nucleus (neglecting the electromagnetic force, and using a 3-dimensional model)

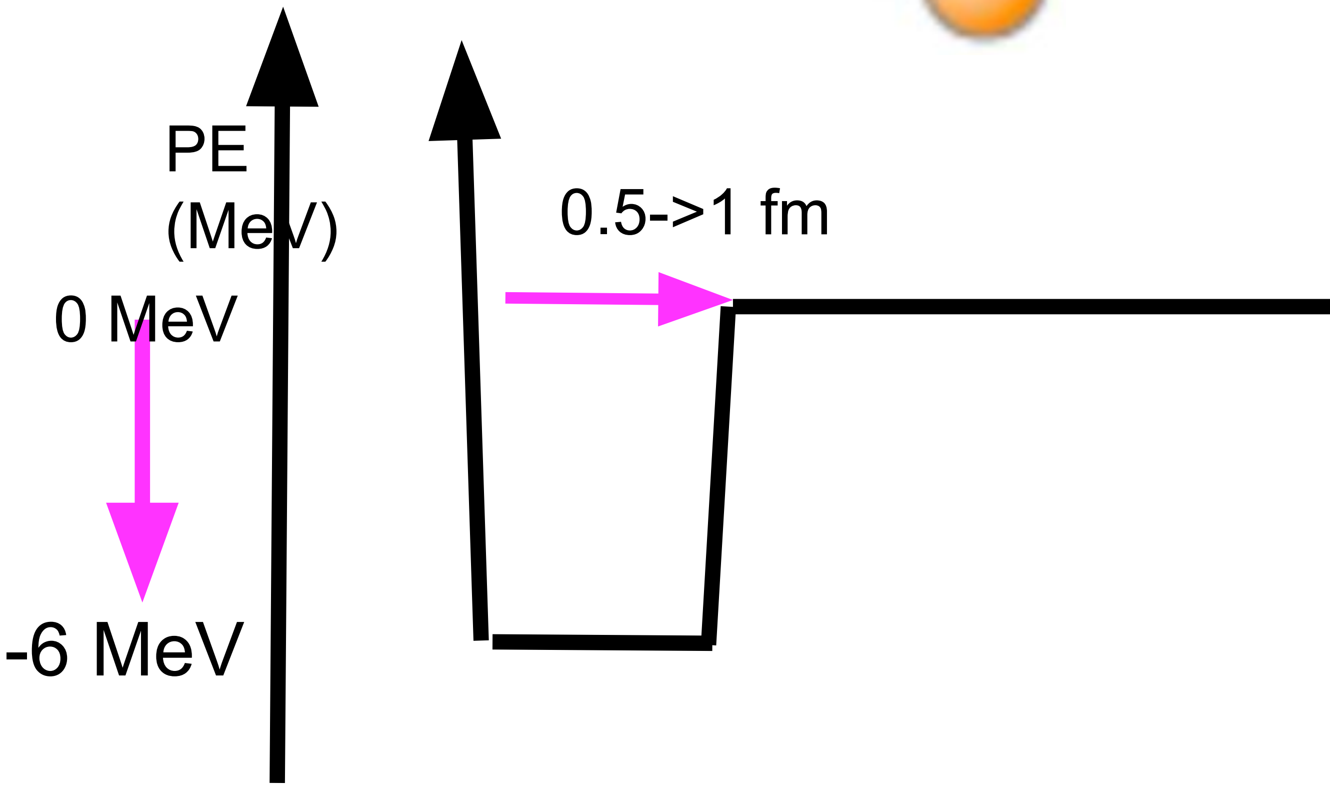
A) 3718 MeV/c^2

B) 3736 MeV/c^2

C) 3754 MeV/c^2

D) 3770 MeV/c^2

E) NOTA



Given the PE curve shown, if the `range' of the strong force is 2 fm, then the maximum number of 1 fm diameter nucleons such that they all interact in 3d is:

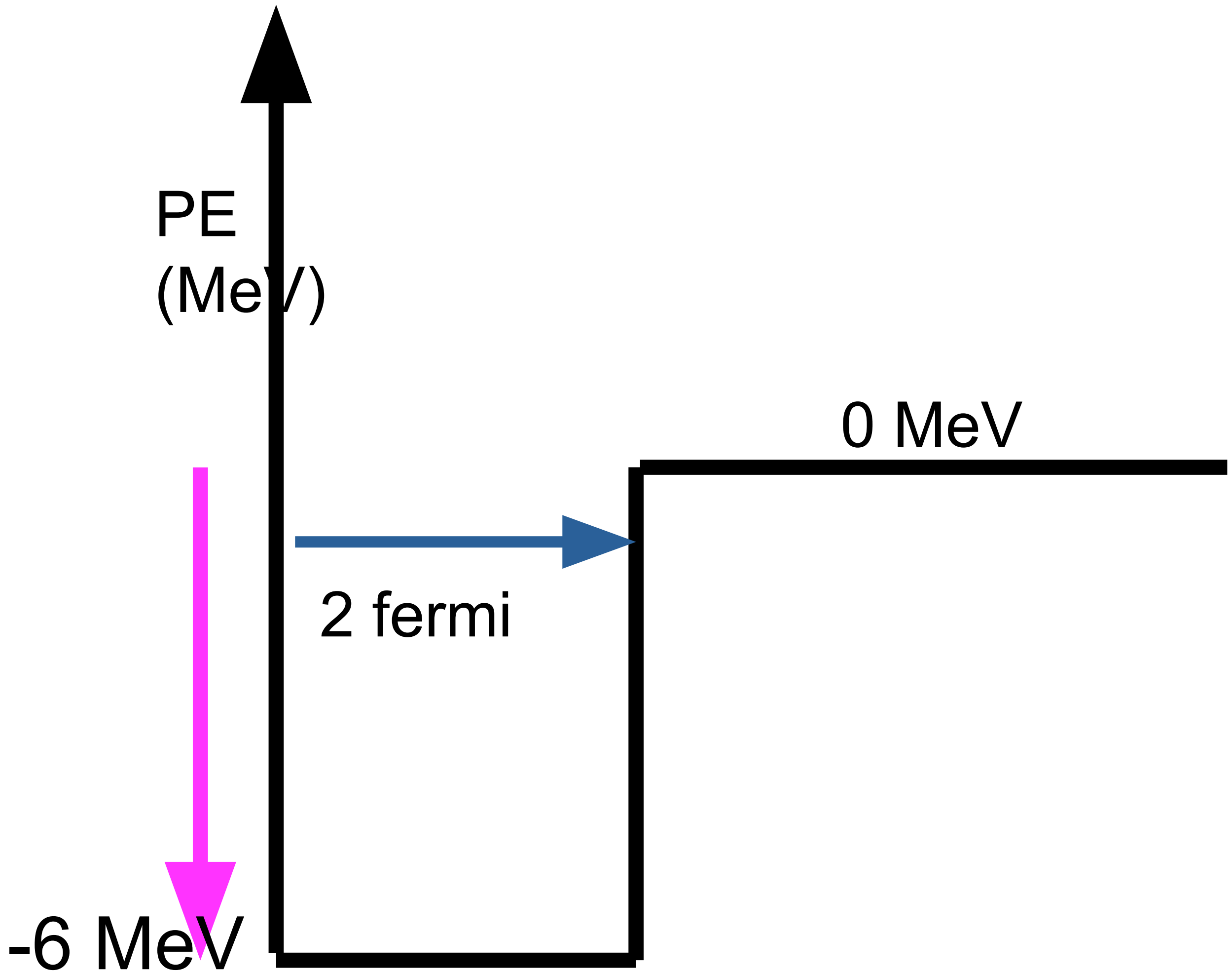
A) 4

B) 10

C) 22

D) 34

E) NOTA



If we now add an electromagnetic force, with PE=+1 MeV/r[fm], then the most likely 1-dim Li configuration (in 1d) is:

A) pppnnn

B) pnpnpn

C) pnpnnp

D) NOTA

If the range were 1.5 fm, then, in a *simplified, one-dimensional model*, accounting for the strong nuclear force only, with diameter(p)=1 fm, m_p=938 MeV/c^2 and m_n=939 MeV/c^2, the mass of ^6_3Li would be:

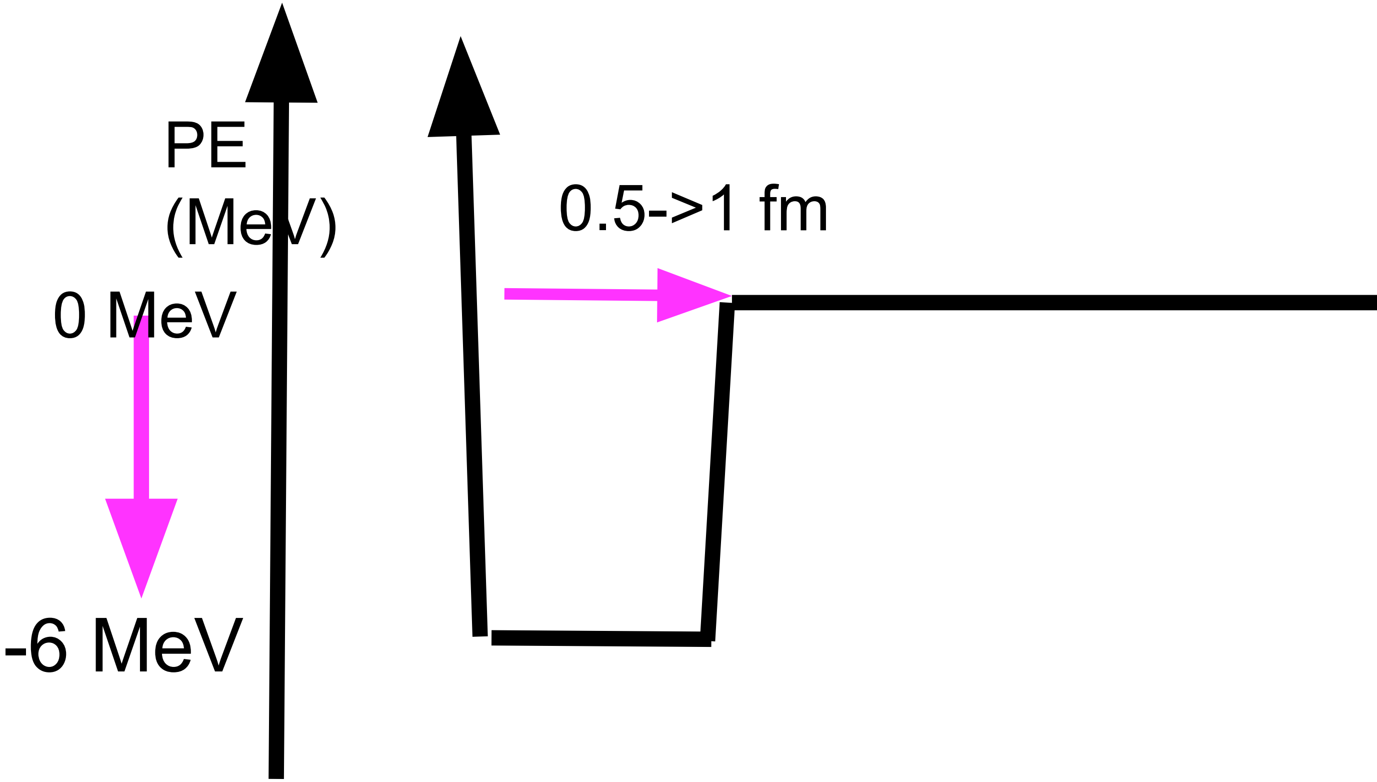
A) 5631 MeV/c^2

B) 5583 MeV/c^2

C) 5577 MeV/c^2

D) 5541 MeV/c^2

E) NOTA



If we now add an electromagnetic force, with PE=+1.44 MeV/r[fm], then the previous answer becomes:

A) Smaller by 0.7 MeV

B) Larger by 0.7 MeV

C) Larger by 1.5 MeV

D) Smaller by 1.5 MeV

E) NOTA

If the PE range were doubled, the number of nucleons that would fit in 3-dimensions would grow by a factor:

A) 1

B) 2

C) 4

D) 8

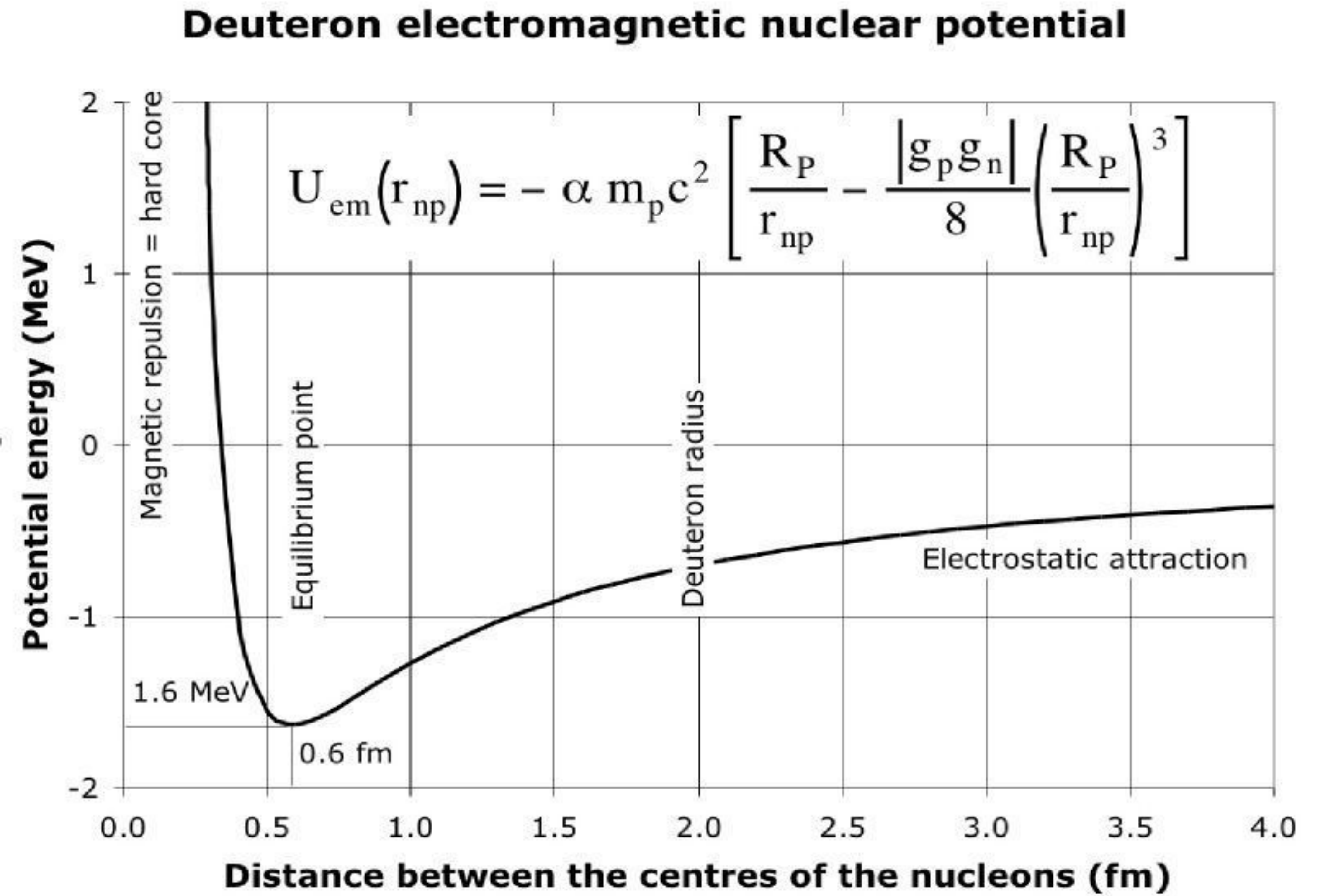
E) NOTA

The true answer to the previous problem for the entire Helium atom, taking into account all the electrical force effects, is:

A) Smaller

B) Larger

C) The same



Deuteron electromagnetic nuclear potential
$$U_{em}(r_{np}) = -\alpha\, m_p c^2 \left[\frac{R_P}{r_{np}} - \frac{|g_p g_n|}{8} \left(\frac{R_P}{r_{np}} \right)^3 \right]$$
Magnetic repulsion = hard core
Equilibrium point
Deuteron radius
Electrostatic attraction
1.6 MeV
0.6 fm
Potential energy (MeV)
2
1
0
-1
-2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Distance between the centres of the nucleons (fm)

Given that the `range' of the strong nuclear force=2.1 fm, the PE "depth" is -3 MeV, and the diameter of one nucleon is 1 fm, how much E is released (neglecting the electrical force) when 3 protons and 3 neutrons fuse, in one dimension to form Lithium (assume pnpnpn)?

A) 25.25 MeV

B) 27 MeV

C) 36 MeV

D) 25.5 MeV

E) NOTA

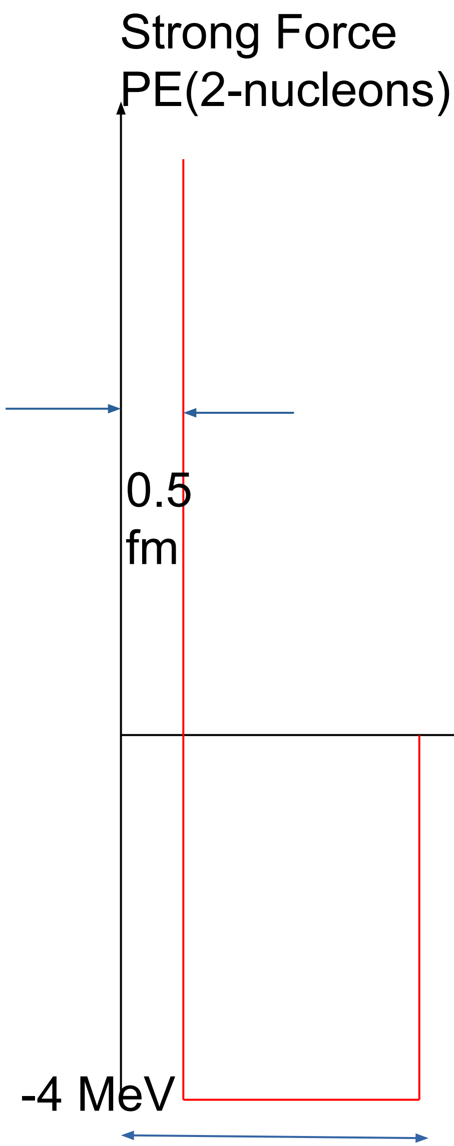
The binding energy, in 3 dimensions would be:

A) Smaller than in 1-d

B) Larger than in 1-d

C) The same

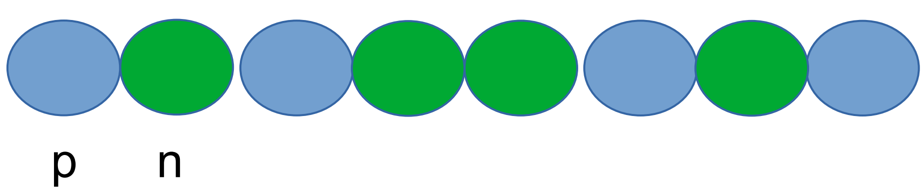
$m_p+m_n+PE_i+KE_i=\boldsymbol{m_p+m_n+PE_f}+KE_f+heat_{Ext}=\boldsymbol{m_{pn}}+heat_{Ext}$



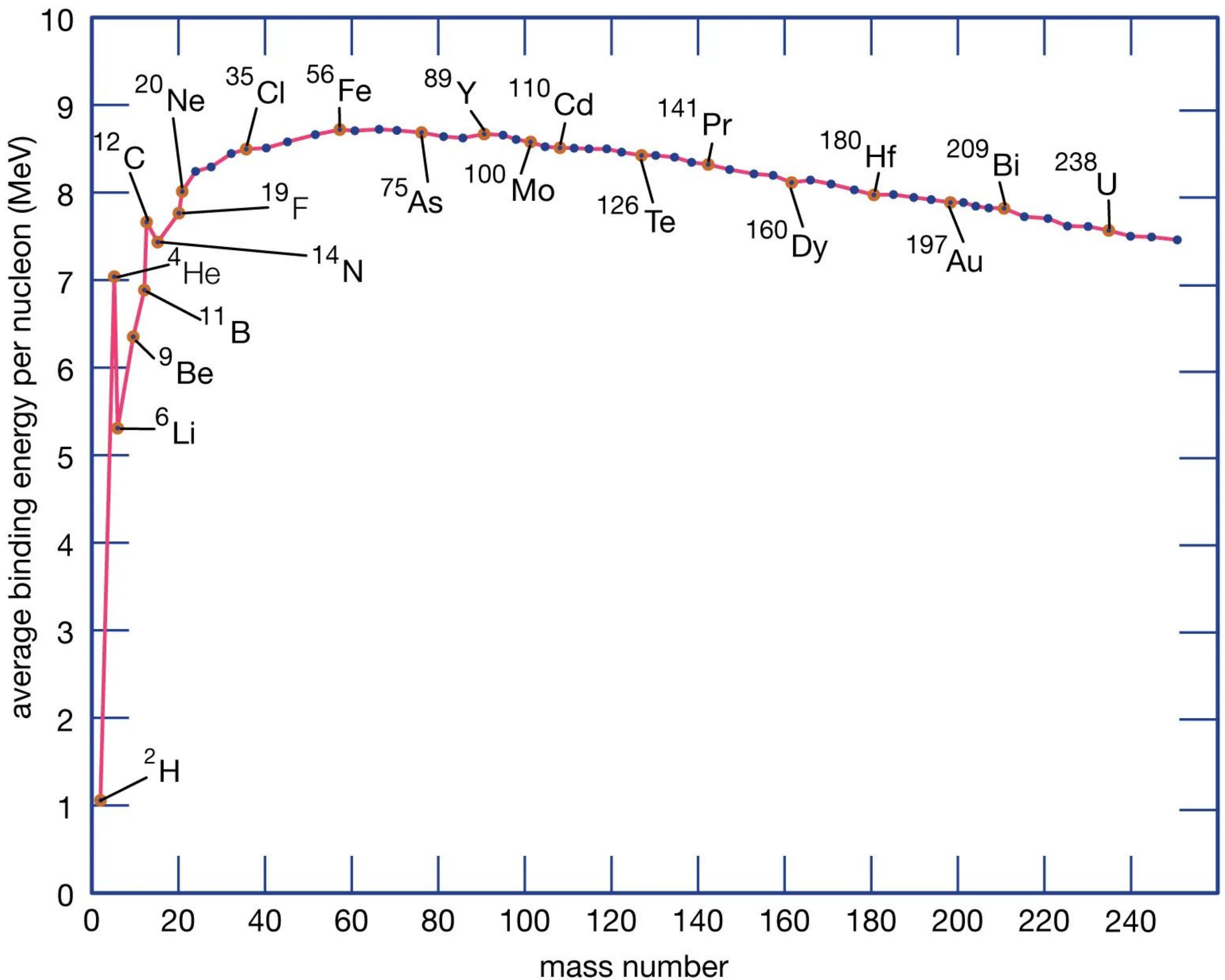
Electrical PE=kq_pq_p/r; Strong PE=-4 MeV for any two nucleons within 2.5 fm of each other. Nucleon diameter=1 fm

Total Strong PE: count combinations with radii within 2.5 fm:
(1,2),(1,3),(2,3), (2,4), (3,4), (3,5), (4,5), (4,6), (5,6), (5,7), (6,7), (6,8),(7,8)
13*-4 MeV/bond=-52 MeV strong force energy

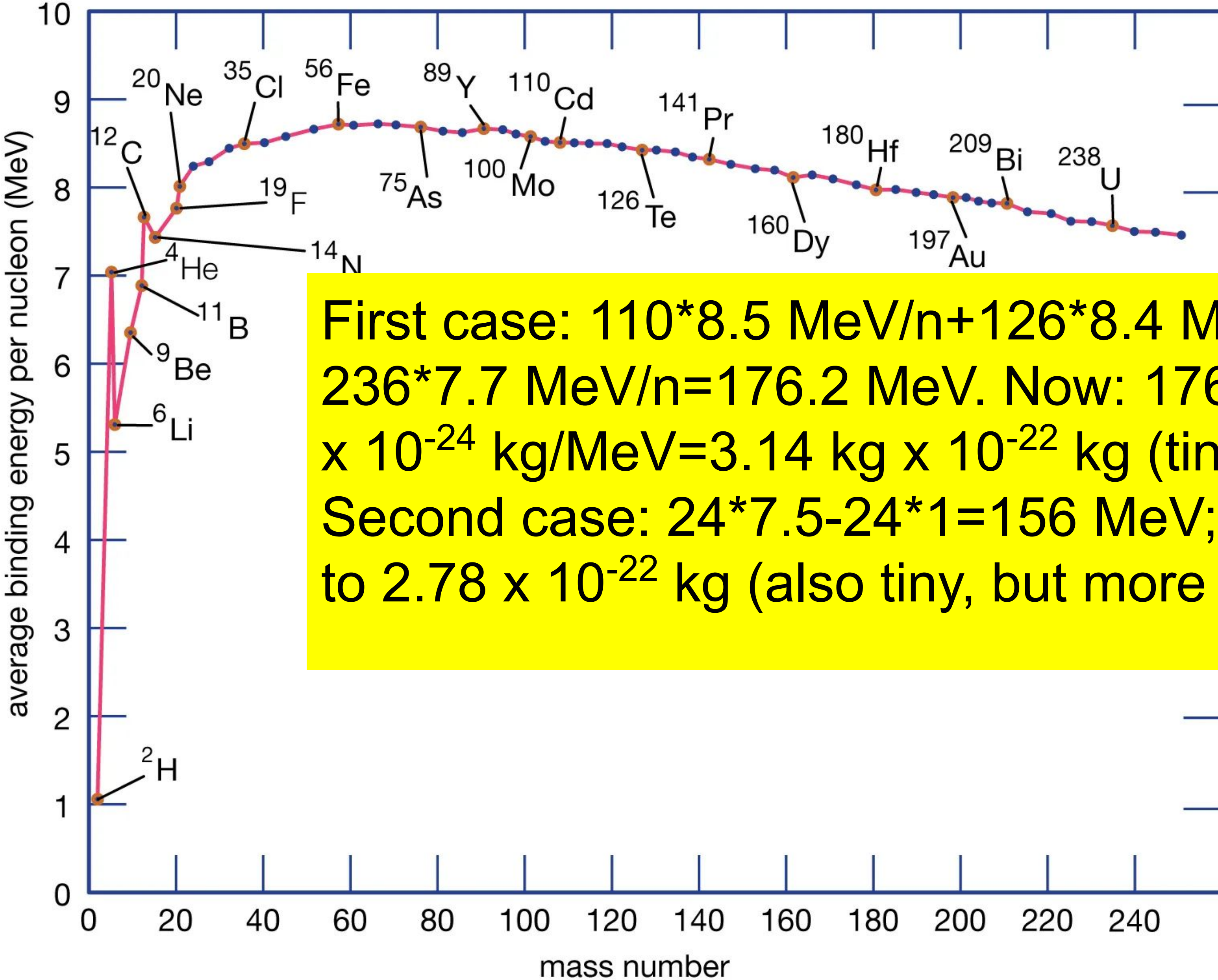
Total Electrical PE (positive) for protons only; calculate kq_1q_2/r:
9e9*1.6e-19*1.6e-19/r=2.304e-28 Joules/r [meters]; now I mutiply through by 1 eV/1.6e-19 J and 1e-15m/fermi and get 1.44e6 eV/r[fm]
PE=+1.44 MeV/r(fm), six electrical PE combinations (1,3), (1,6), (1,8), (3,6), (3,8), (6,8), so total electrical PE=1.44/2.+1.44/5.+1.44/7.+1.44/3.+1.44/5.+1.44/2.=2.70 MeV
Total formation energy=-49.3 MeV, as heat when nucleons coalesce



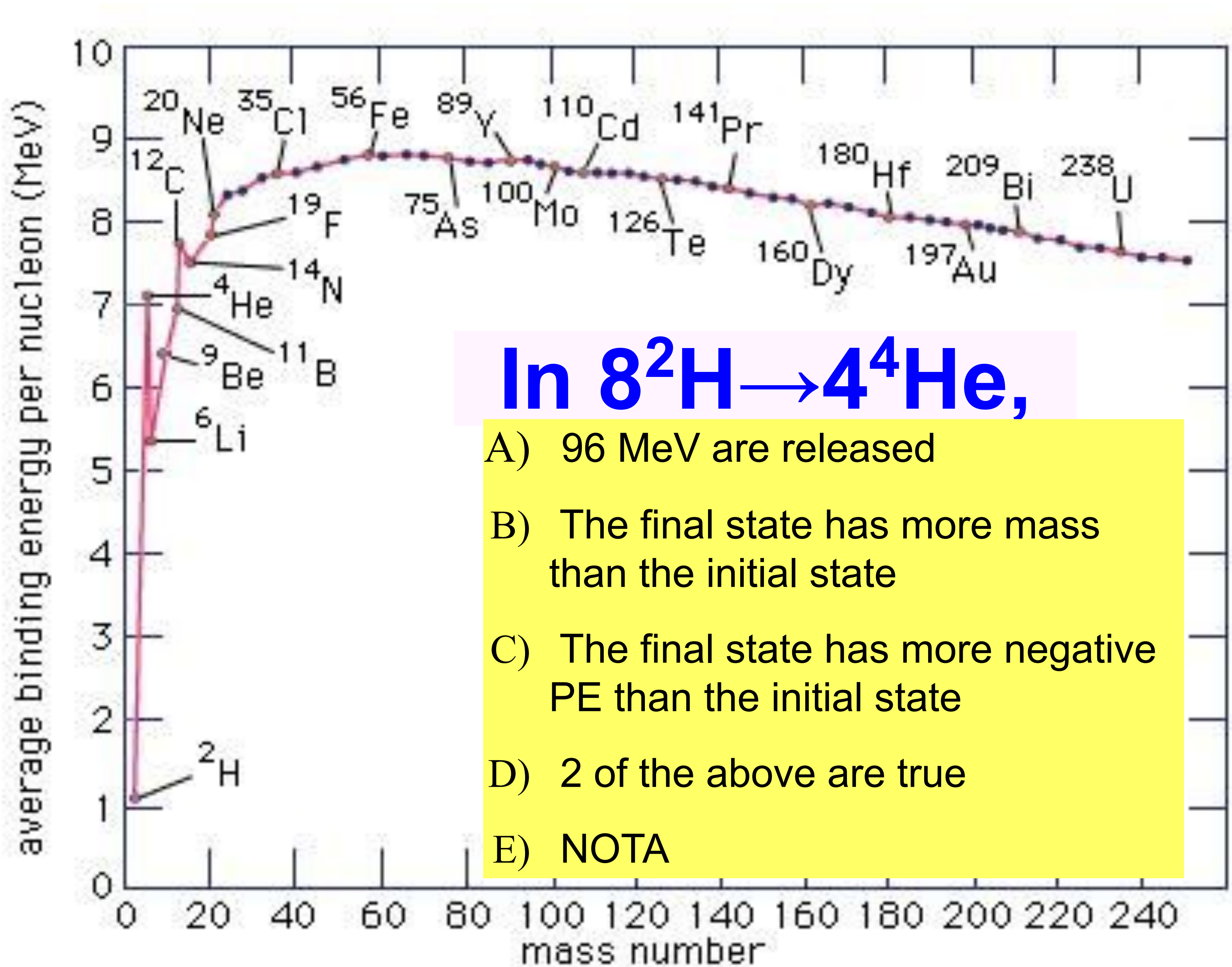
determine the mass (in kg) of ^{236}U lost via ^{238}U->^{126}Te+^{110}Cd, and also 12^{2}H->2^{12}C.



determine the mass (in kg) of ^{236}U lost via $^{238}U \rightarrow ^{126}Te + ^{110}Cd$, and also $12\,^{2}H \rightarrow 2\,^{12}C$.



First case: 110*8.5 MeV/n+126*8.4 MeV/n - 236*7.7 MeV/n=176.2 MeV. Now: 176.2 MeV*1.783 x 10^{-24} kg/MeV=3.14 kg x 10^{-22} kg (tiny!!);
Second case: 24*7.5-24*1=156 MeV; corresponds to 2.78 x 10^{-22} kg (also tiny, but more explosive!)



In $8\,^{2}H \rightarrow 4\,^{4}He$,

A) 96 MeV are released

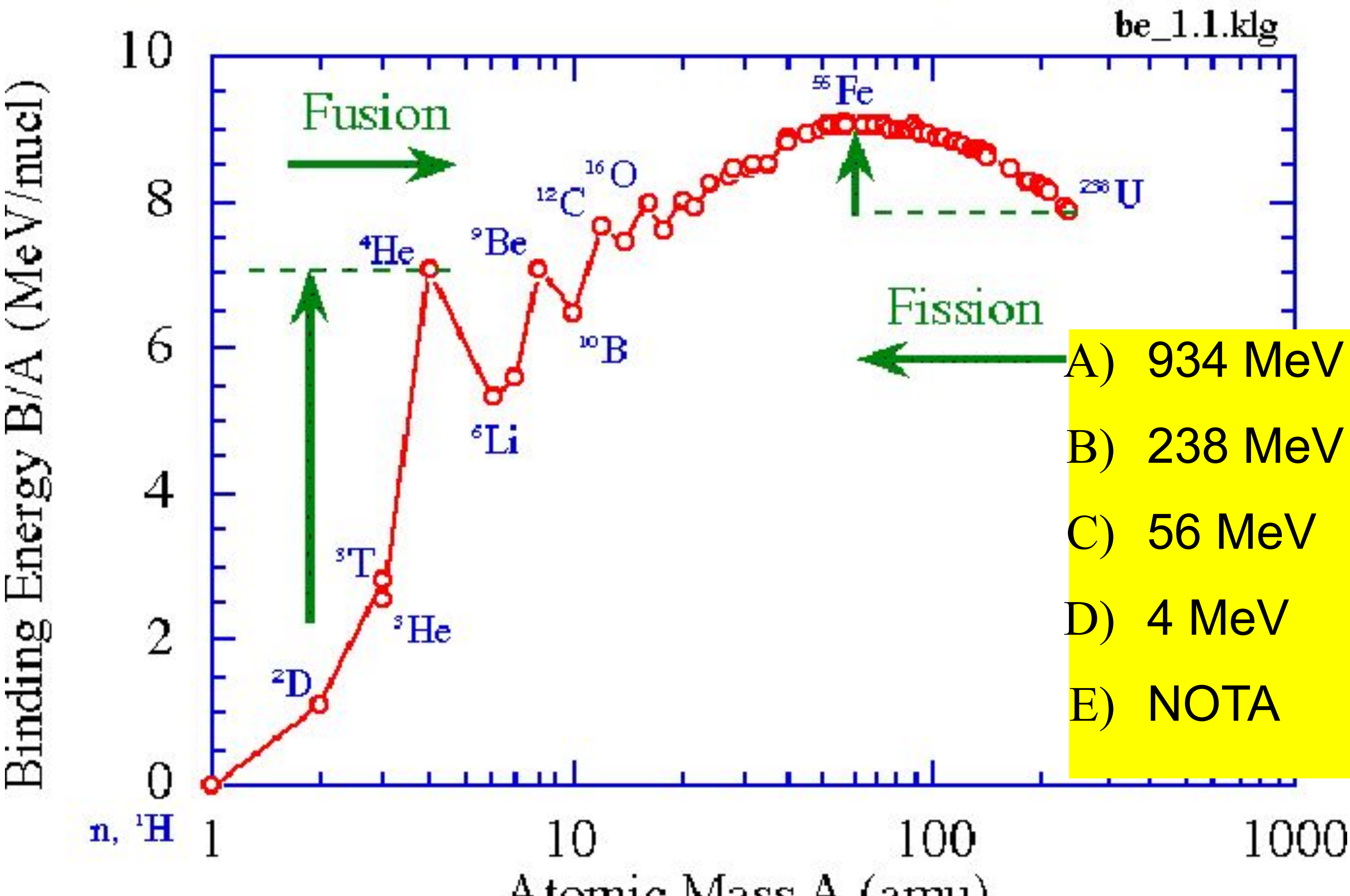
B) The final state has more mass than the initial state

C) The final state has more negative PE than the initial state

D) 2 of the above are true

E) NOTA

In $^{238}_{92}U \rightarrow 3(^{58}_{26}Fe) + X$, the heat generated=



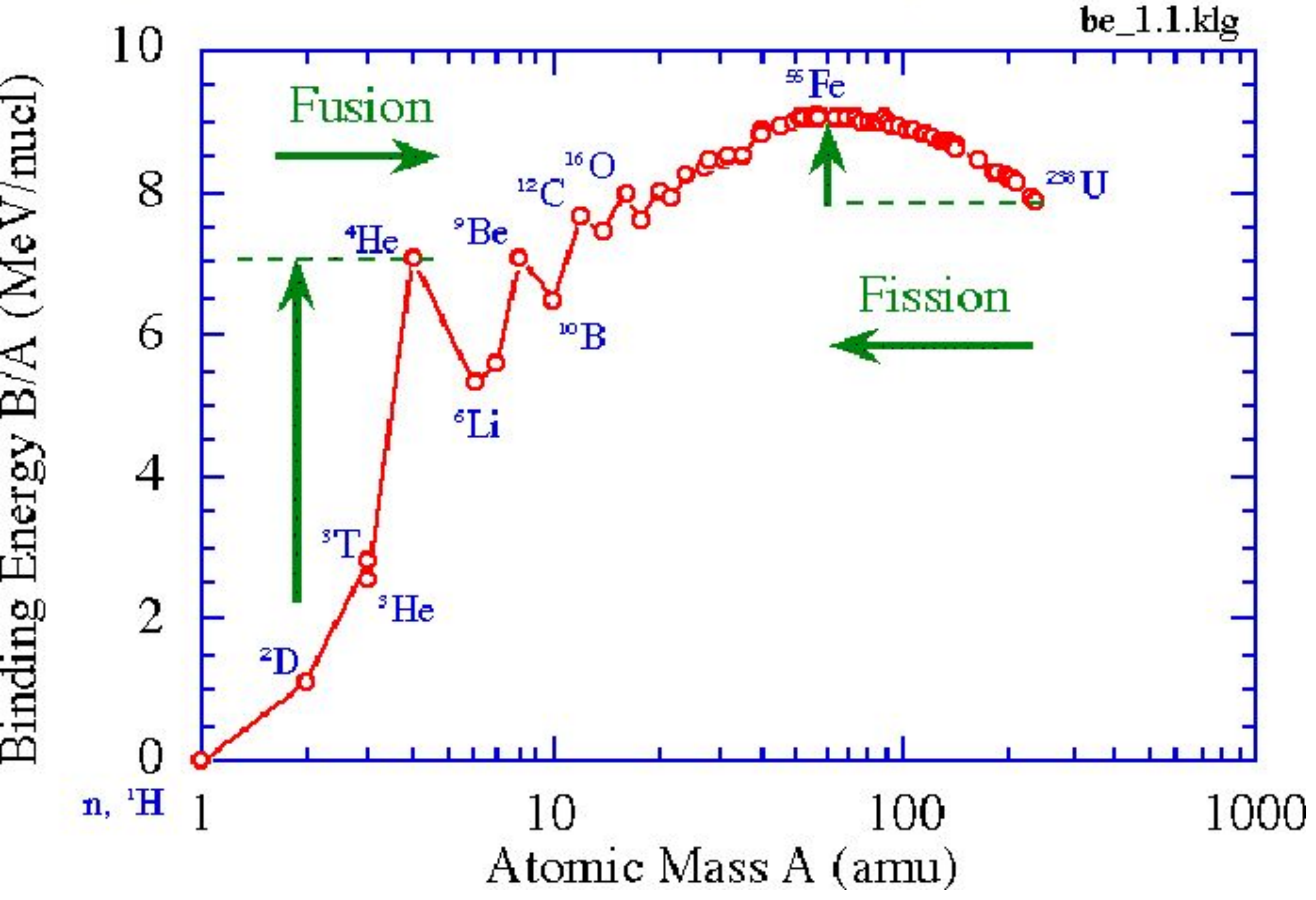
A) 934 MeV

B) 238 MeV

C) 56 MeV

D) 4 MeV

E) NOTA



be_1.1.klg
Binding Energy B/A (MeV/nucl)
Atomic Mass A (amu)
Fusion
Fission
56Fe
16O
12C
238U
4He
9Be
10B
6Li
3T
3He
2D
n, 1H
0
2
4
6
8
10
1
10
100
1000

Which would have the effect of increasing the energy released in a Uranium fission reaction?

A) Increasing the strength of the electric force

B) Increasing the range of the nuclear force

C) Decreasing the strength of the nuclear force

D) Two of the above

E) All of the above

Which would have the effect of increasing the energy released in a Hydrogen fusion reaction?

A) Increasing the strength of the electric force

B) Increasing the range of the nuclear force

C) Decreasing the strength of the nuclear force

D) Two of the above

E) All of the above

Sketch the NBE curve if the range of the strong force were increased

Wave Functions

The uncertainty in position associated with a 40 kg person moving at 10 m/s (Sydney McGlaughlin-Levrone, of Dunellen, NJ) is about

A) 10^{-10} m

B) 10^{-34} m

C) 10^{-36} m

D) 10^{-32} m

E) NOTA

An electron is in the 1s state in Hydrogen. What is the probability of *measuring* the electron with x>0, y>0 and z>0?

A) ½

B) ¼

C) 1/8

D) 1/16

E) NOTA

An electron has a wave function $\Psi(x)=\sin(2x)$ $(0<x<2\pi)$. The probability that the electron is found at x=1 m relative to x=2 m is:

A) 1.44

B) 1.0

C) 0.598

D) 0

E) NOTA

Two protons and one neutron coalesce, in a 6 MeV deep, 3 fm wide potential, to form ^{3}He. Which is true?

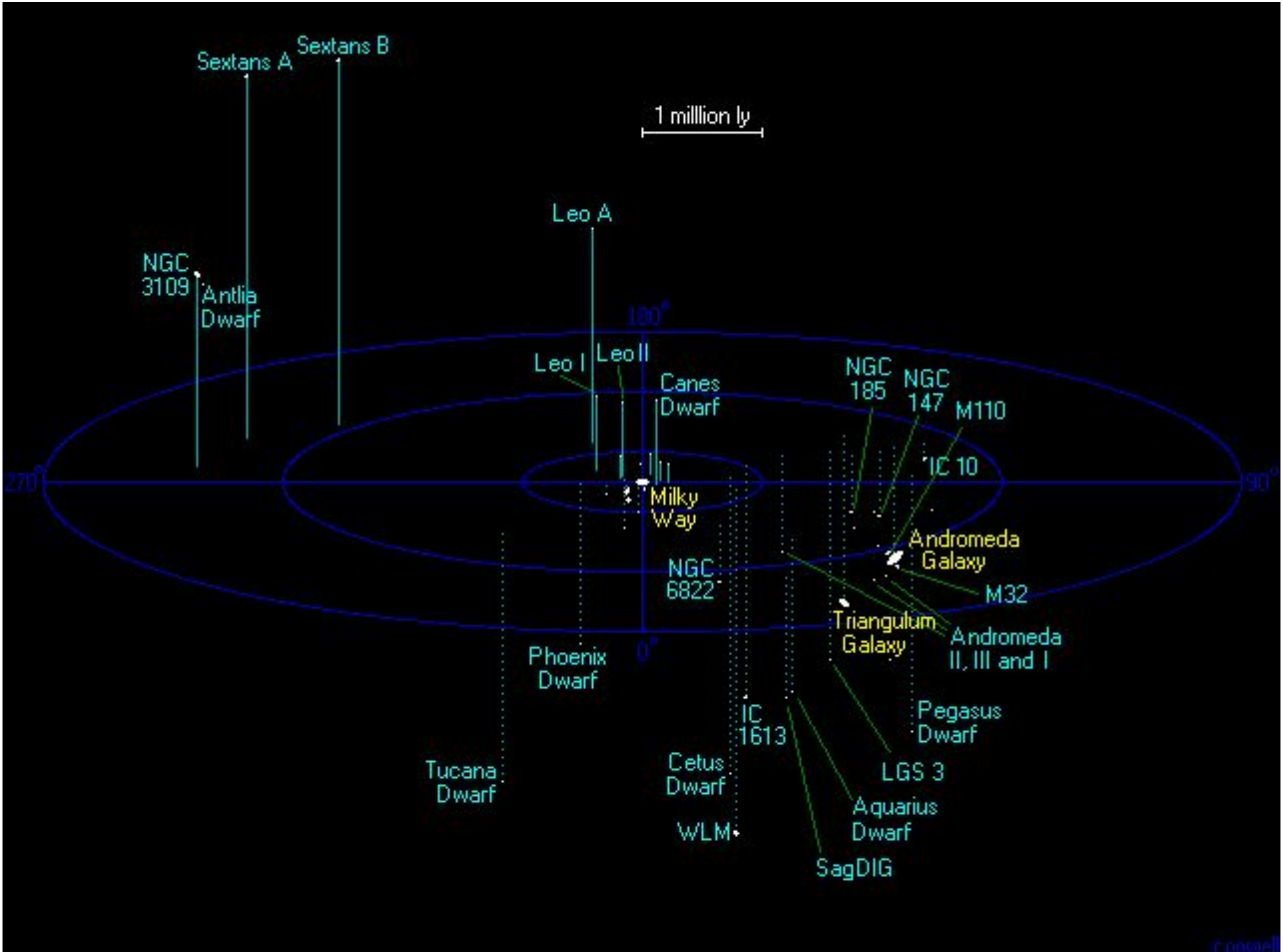
A) The probability of measuring the neutron in the interval 1 fm→2 fm is **always** 1/3, independent of any other measurements

B) The probability of measuring the neutron in the interval 1 fm → 2 fm after one of the protons has been measured in the range 2 fm → 3 fm is ½

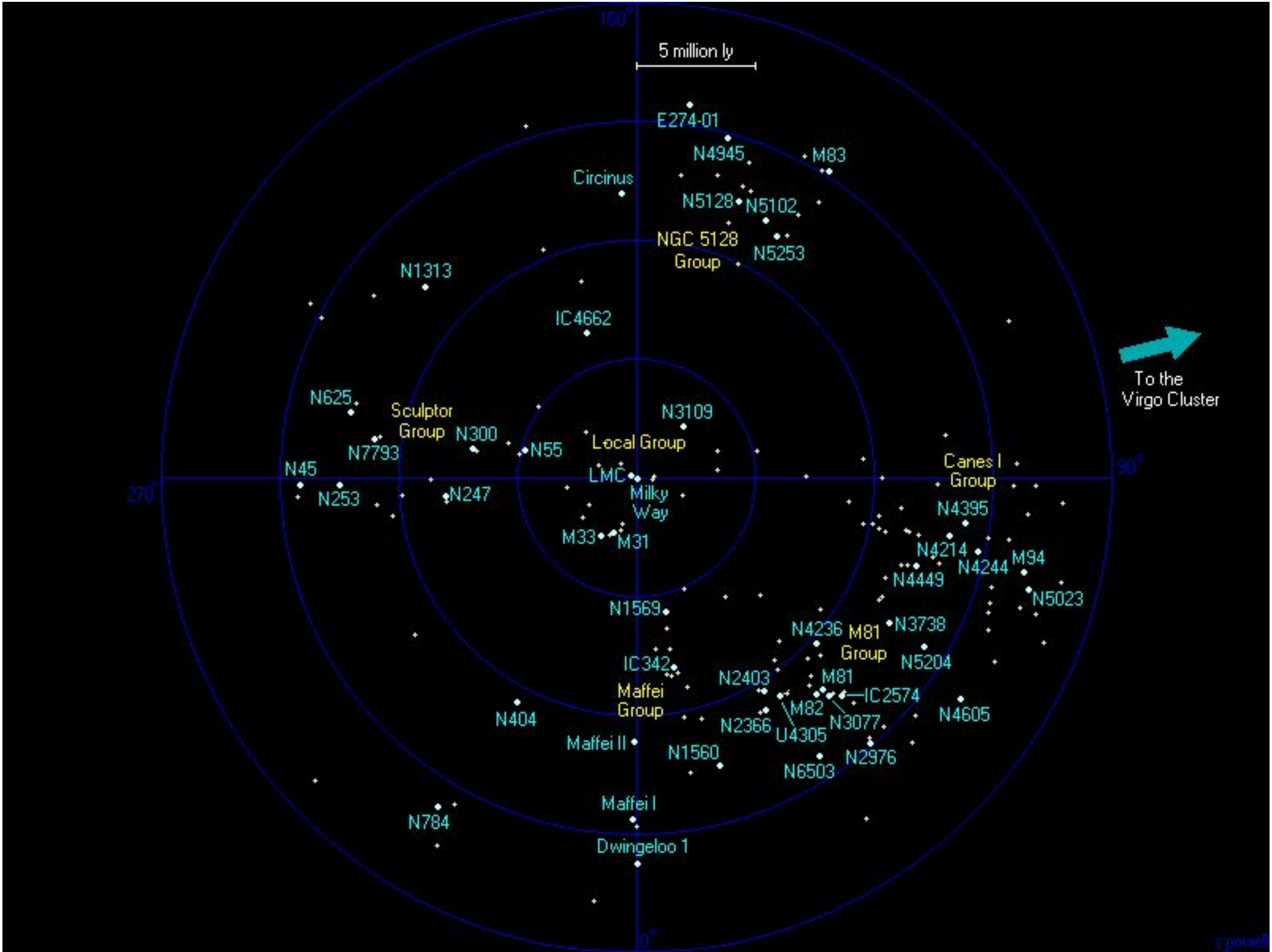
C) The probability of measuring the neutron in the interval 1 fm → 2 fm after one of the protons has been measured in the range 2 fm → 3 fm is 1/3

D) NOTA

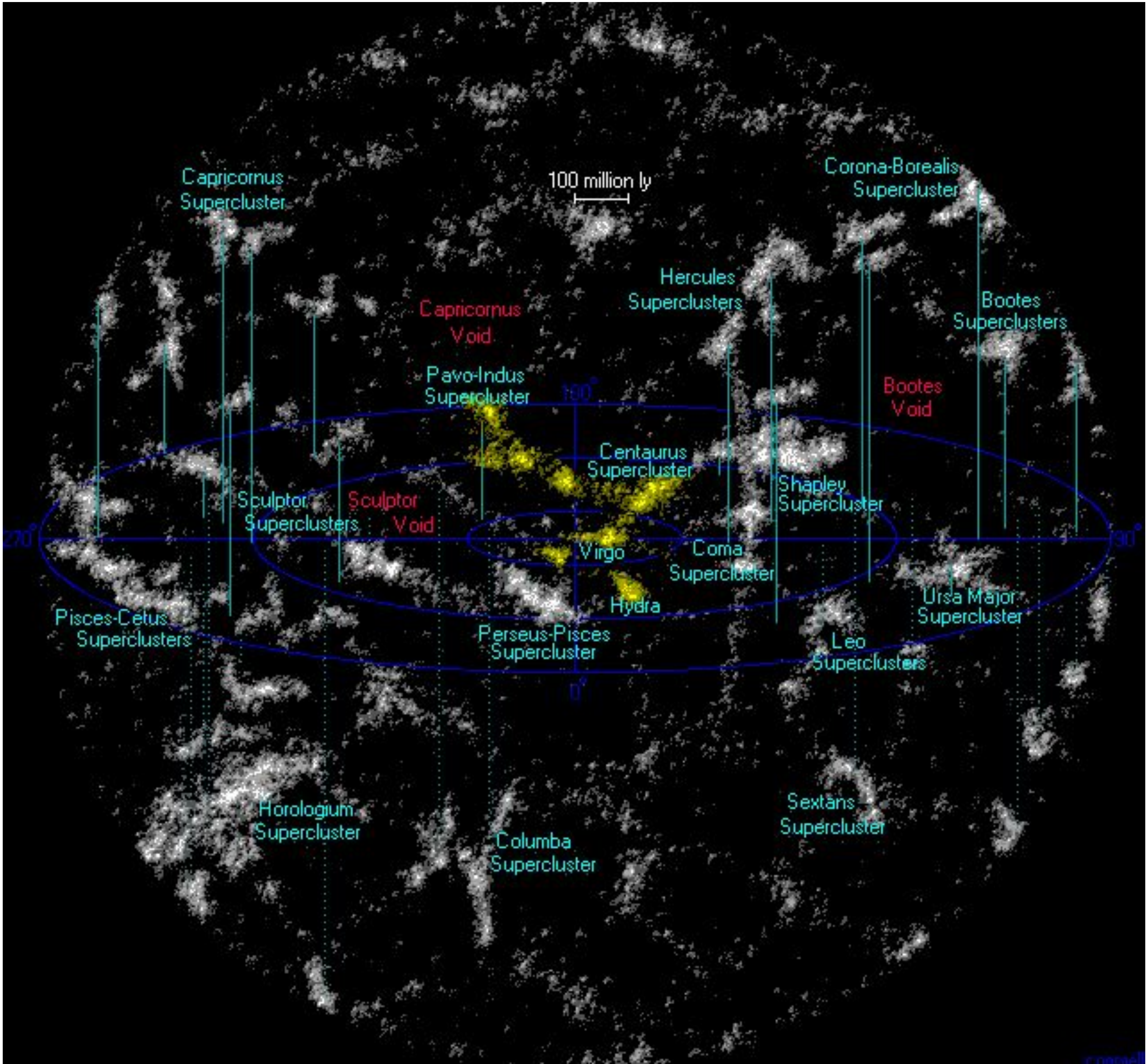
Cosmology-
recall Hydrogen electron: if KE+PE<0; electron is ‘bound’; if KE+PE>0 => unbound



Sextans A
Sextans B
1 million ly
Leo A
NGC 3109
Antlia Dwarf
180°
270°
90°
0°
Leo I
Leo II
Canes Dwarf
NGC 185
NGC 147
M110
IC 10
Milky Way
Andromeda Galaxy
NGC 6822
M32
Triangulum Galaxy
Andromeda II, III and I
Phoenix Dwarf
IC 1613
Pegasus Dwarf
Tucana Dwarf
Cetus Dwarf
LGS 3
Aquarius Dwarf
WLM
SagDIG



180°
5 million ly
E274-01
N4945
M83
Circinus
N5128
N5102
NGC 5128
Group
N5253
N1313
IC4662
To the
Virgo Cluster
N625
Sculptor
Group
N3109
N300
N7793
N55
Local Group
N45
LMC
Canes I
Group
90°
270°
N253
N247
Milky
Way
N4395
M33
M31
N4214
N4244
M94
N4449
N5023
N1569
N4236
M81
Group
N3738
IC342
N5204
N2403
M81
Maffei
Group
IC2574
M82
N3077
N4605
N404
N2366
U4305
Maffei II
N1560
N2976
N6503
Maffei I
N784
Dwingeloo 1
0°



100 million ly
Capricornus Supercluster
Corona-Borealis Supercluster
Hercules Superclusters
Bootes Superclusters
Capricornus Void
Pavo-Indus Supercluster
Bootes Void
180°
Centaurus Supercluster
Shapley Supercluster
Sculptor Superclusters
Sculptor Void
270°
90°
Virgo
Coma Supercluster
Hydra
Ursa Major Supercluster
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
0°
Horologium Supercluster
Columba Supercluster
Sextans Supercluster

Blitzkrieg Cosmology

Cosmology, Friday April 29, 1921:

a) the Universe==the Milky Way (lots of stars)

-nebulae = fuzzy things in the sky?

-Static, eternal

(St. Augustine's dilemma)

(Einstein's dilemma=>'cosmological constant')

b) Olber's Paradox argues against an infinite Universe

1929: Hubble looks at nebulae: "Universe is expanding!"

=>Gamow: play "The Universe, the movie" backwards=>'Big Bang'

Q: does expansion continue forever or does it reach a limit and then implode? (the Big Crunch)

Is PE(total)+KE(total) <,=,>0?

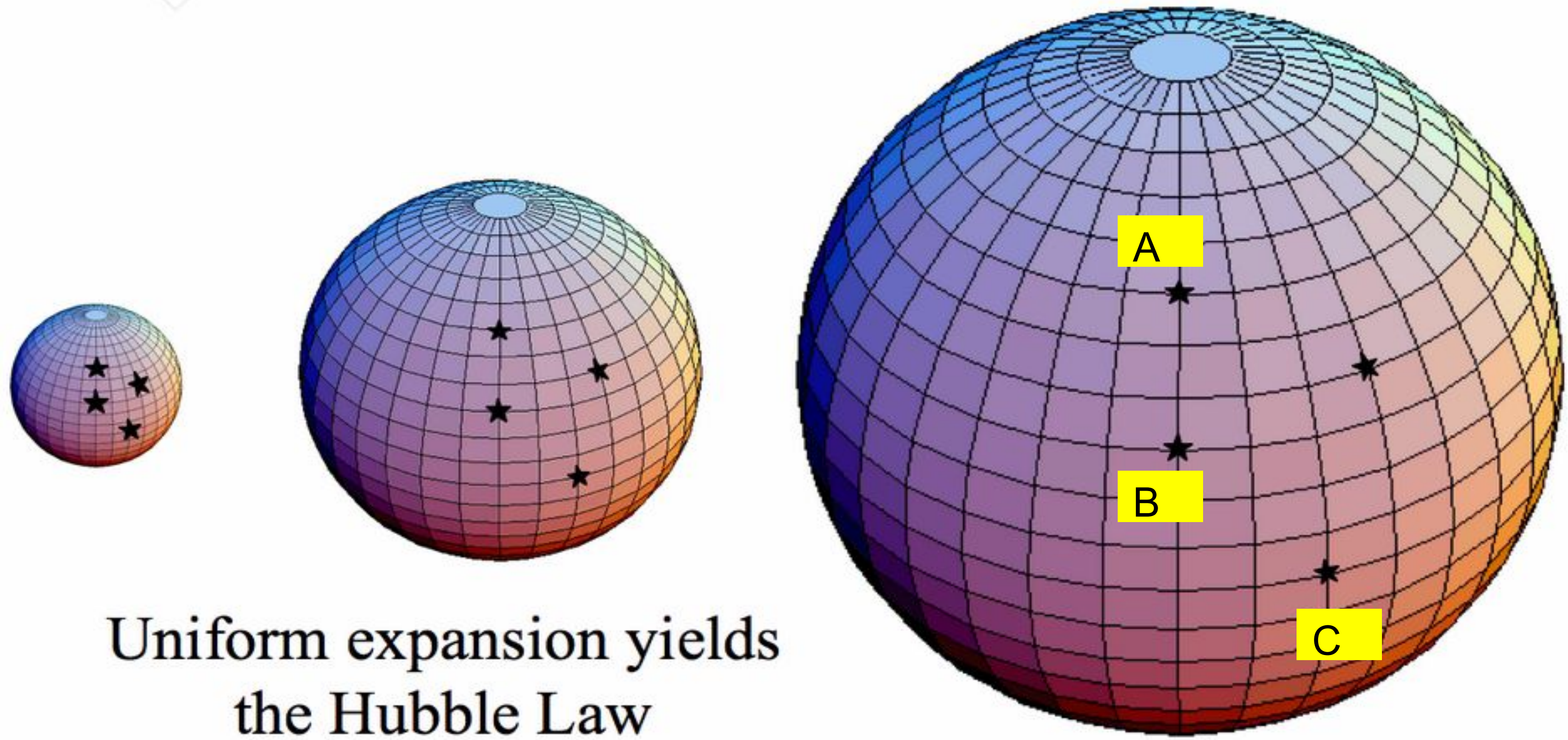
(recall PE for attractive forces (+/-, gravity) negative!

Cosmological task: calculate total (negative) gravitational PE and compare with KE. Complication: "Dark Matter"

Comment on length scales: 1 Mpc~d(Andromeda,Milky Way); 1 pc=3.26 light-yr

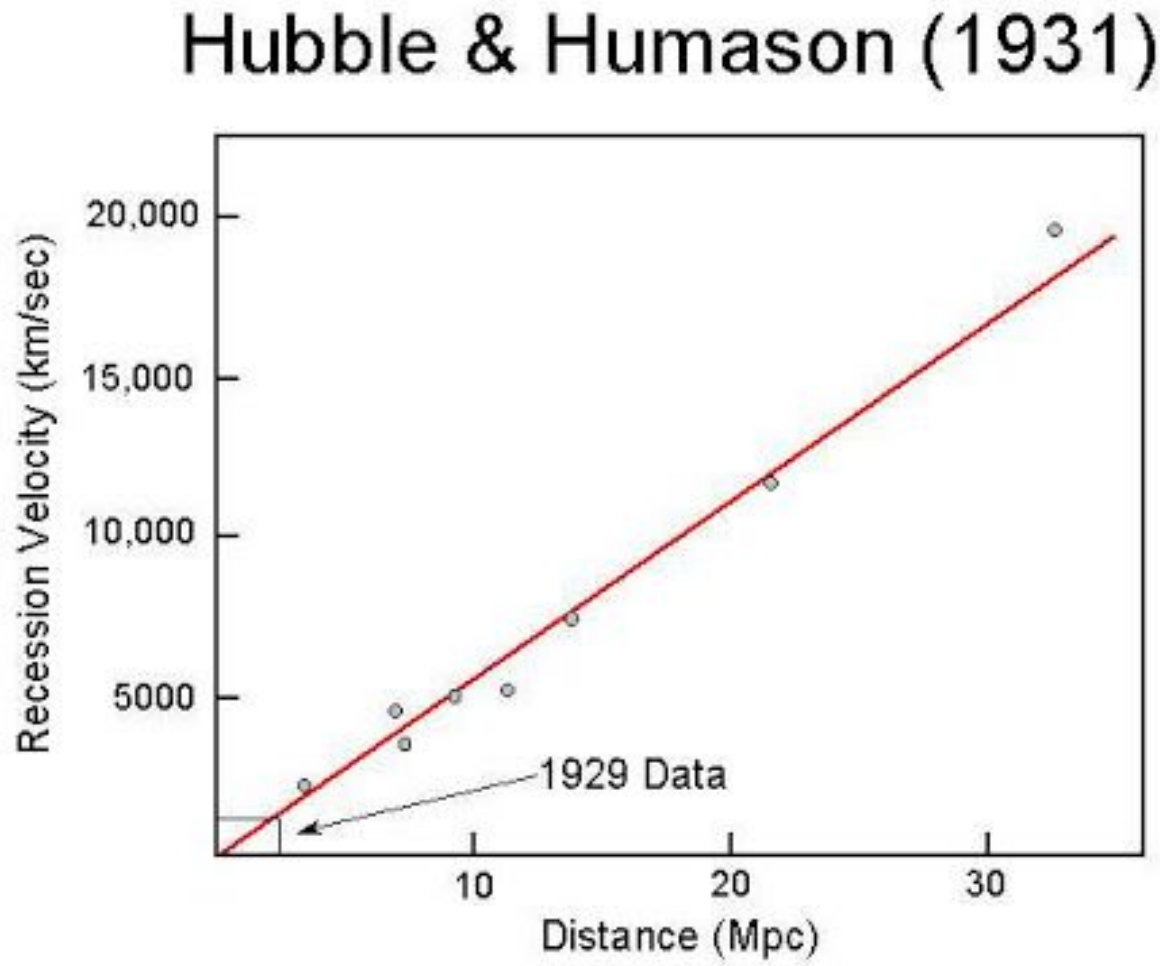
size of visible Universe~28,519 Mpc

If, at t=0, d(A→B)=1 Mpc and d(A→C)=2 Mpc, and A and B separate by 138.8 km in two seconds, then in four seconds, A and C separate by: A) 138.8 km B) 277.6 km C) 555.2 km D) NOTA



'Finite and unbounded'

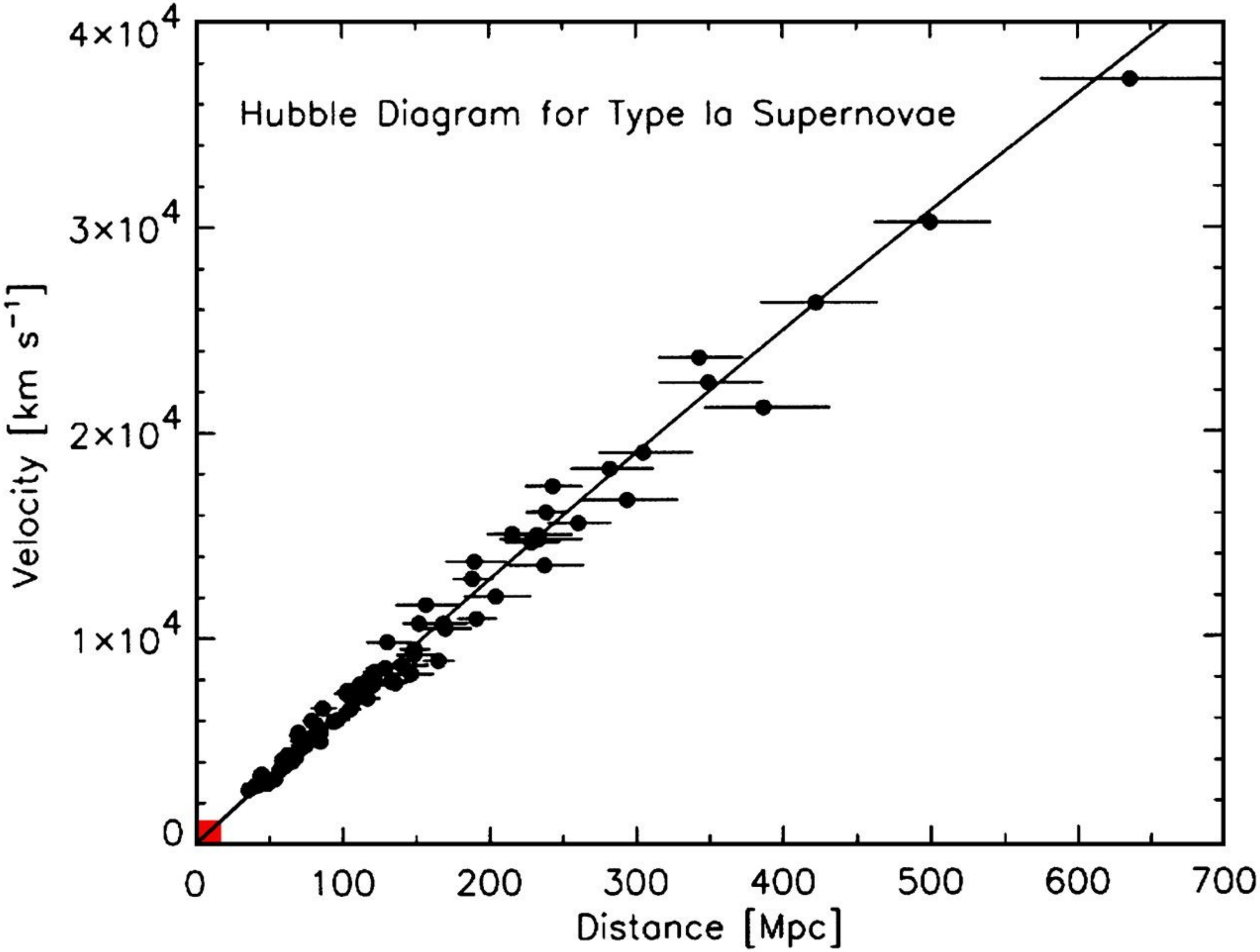
From these data, H_0 is closest to:



A) 1929 km/s/Mpc
B) 67 km/s/Mpc
C) 20000 km/s/Mpc
D) 600 km/s/Mpc

Given that it takes 8 minutes for light from the sun to reach Earth...

From the curve shown, in one minute, two galaxies in neighboring super-clusters (d=100 Mpc) would separate by a distance:



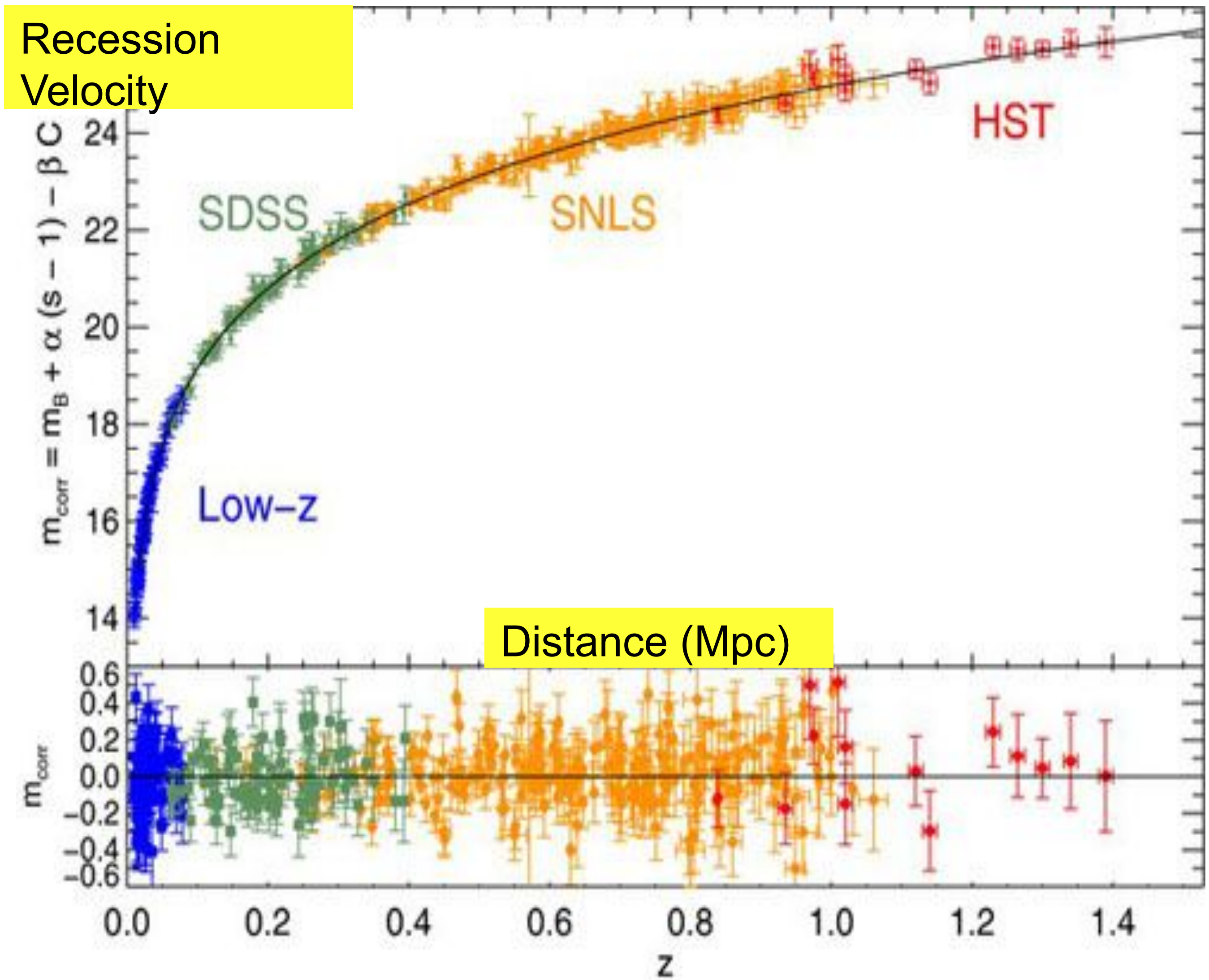
A) 500 km
B) 30000 km
C) 100 km
D) NOTA

Based on the curve shown, you would conclude that:

A) The U expansion is constant

B) The expansion is decelerating

C) The expansion is accelerating



If the Hubble constant were smaller,

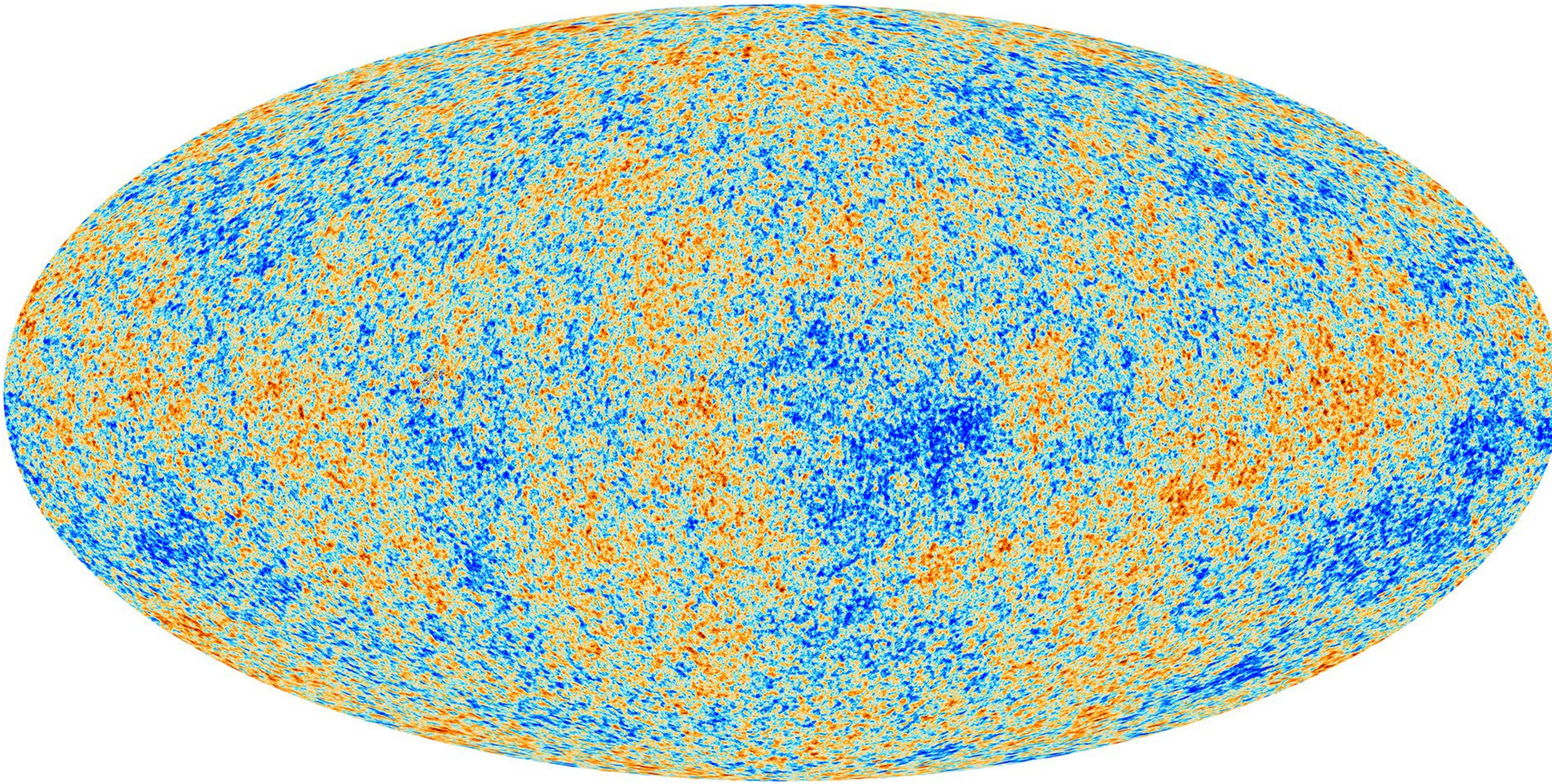
A) The night sky would be brighter

B) The Universe would be more likely to undergo a ‘Big Crunch’

C) Both of A) and B)

D) Neither of A) or B)

The Cosmic Microwave Background



From Lawrence, KS, you look into the night sky and see the cosmic microwave background coming at you from all directions. From that, you conclude that:

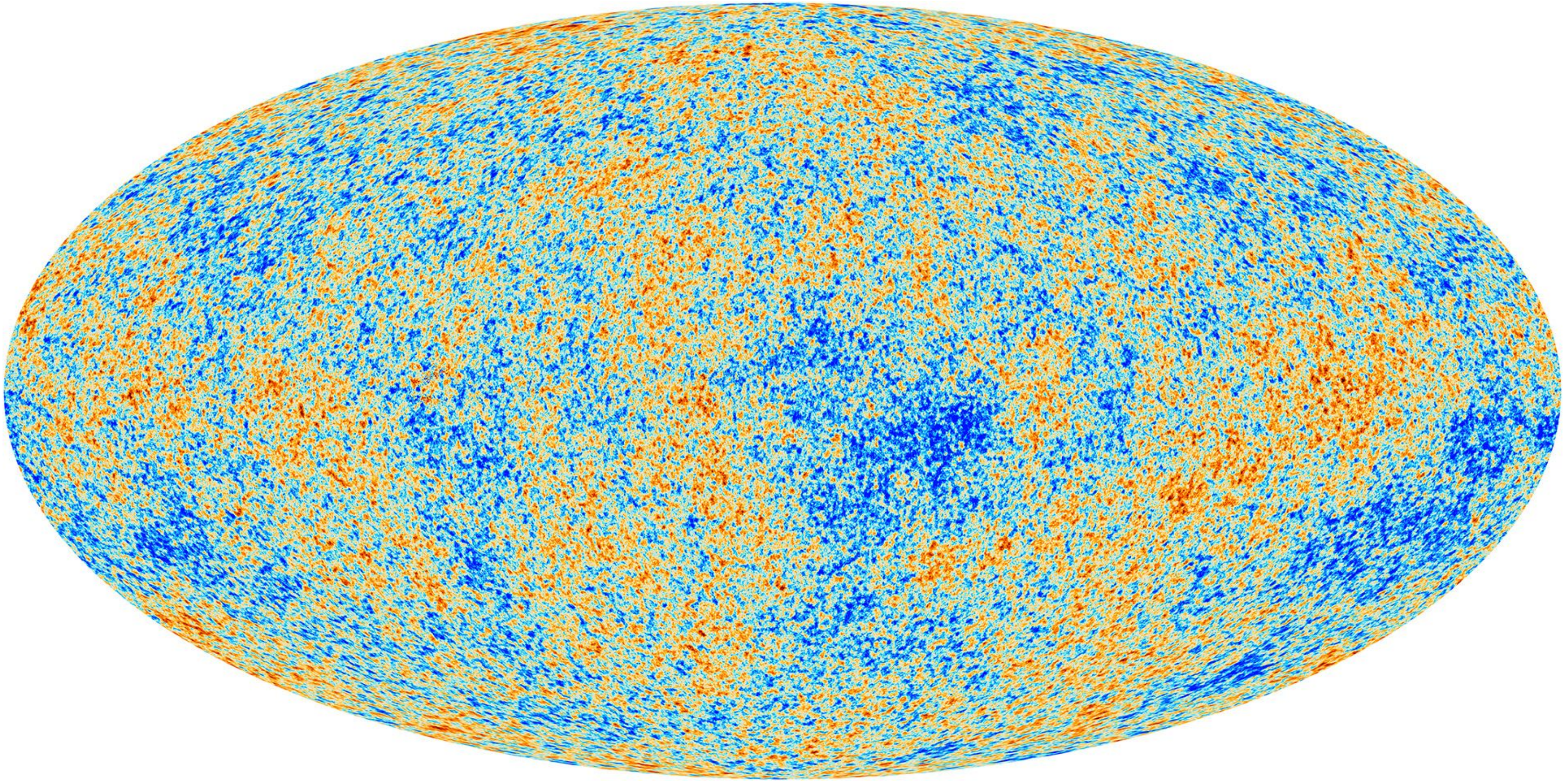
A) The Earth is the center of the Universe

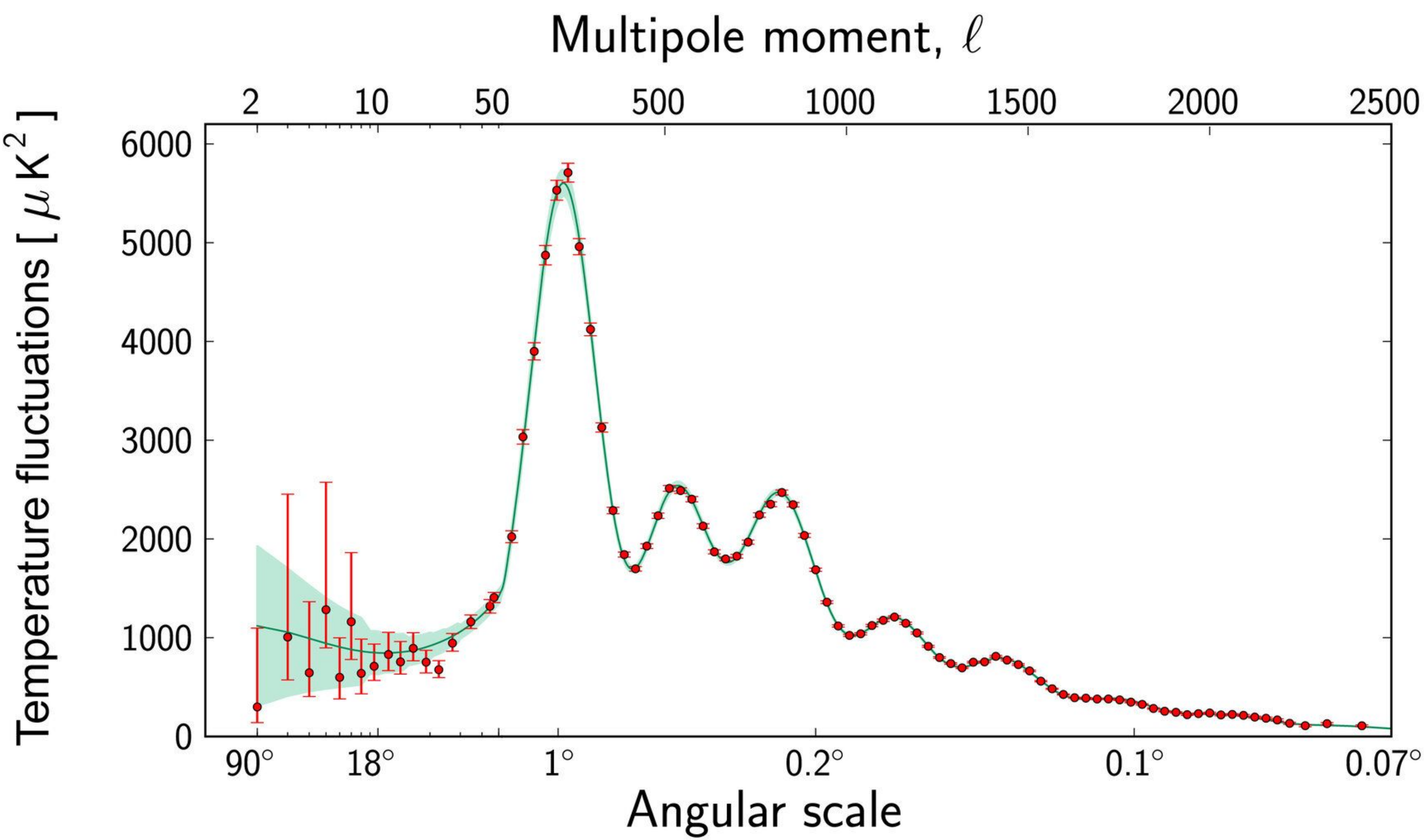
B) The Universe is infinite

C) Either A) or B)

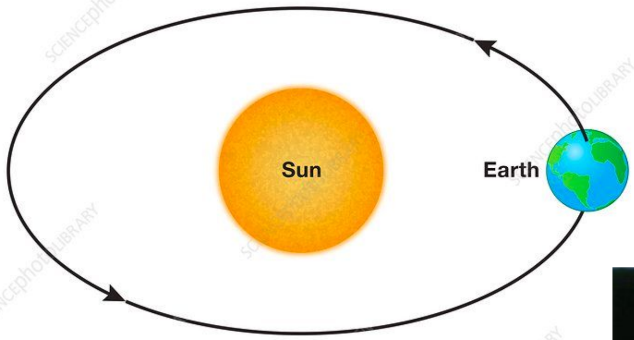
D) Neither A) or B)

Based on the “map” shown, the greatest amount of “power” occurs at angular scales of:
A) 180º, B) 90º,C) 22.5º

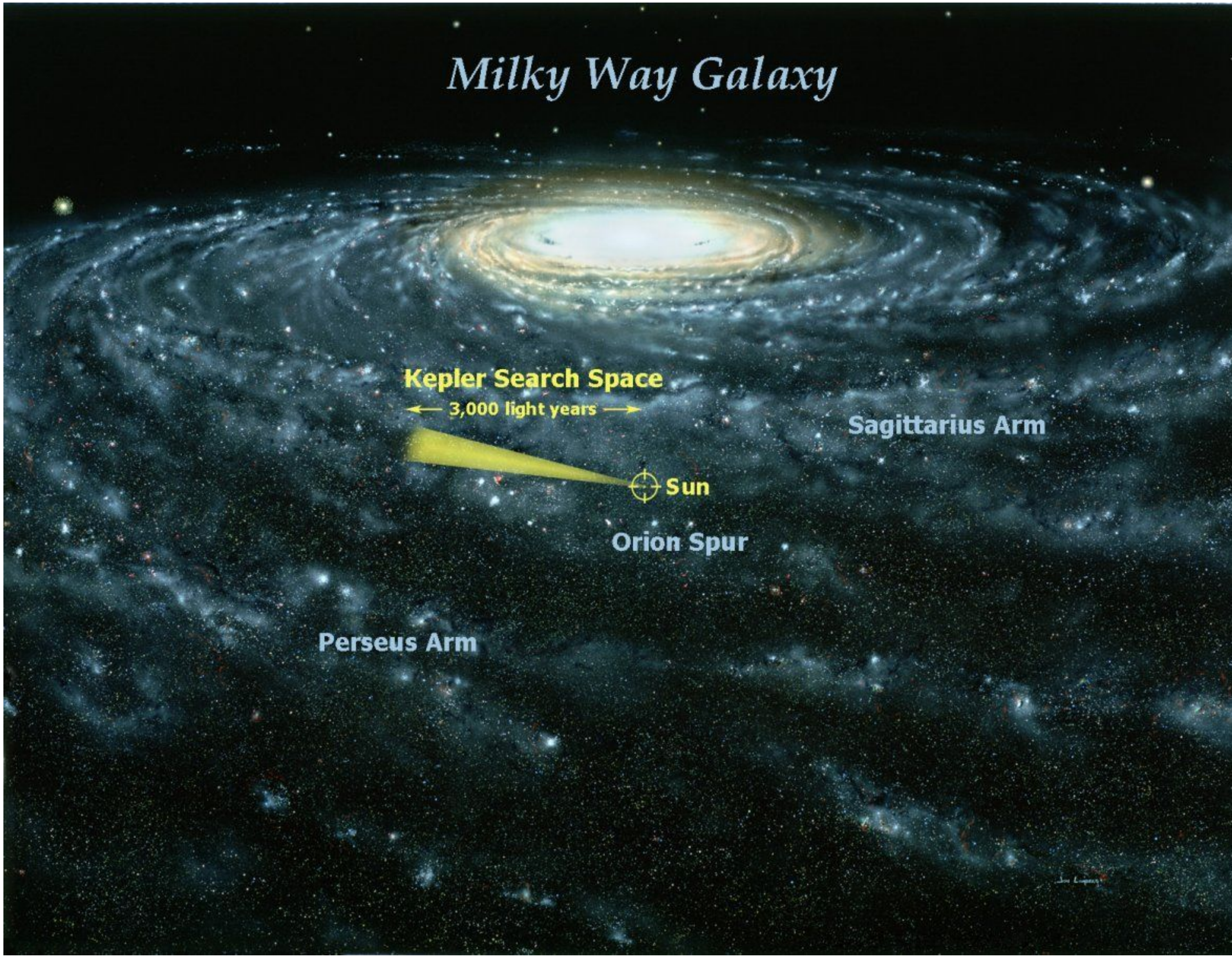




Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μK^2]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale



$M_e v_E^2/r_E = GM_E M_{Sun}/r^2$



Mass of Galaxy=N_{stars} x M_{Sun}

A spiral galaxy consists of 5×10^4 stars identical to our sun, which has a mass of 2×10^{30} kg. Given that, you conclude that the spiral galaxy is

A) 0% dark matter

B) ~20% dark matter

C) ~40% dark matter

D) >60% dark matter

Light is measured at Earth from stars, at the periphery (10^{12} m) and also at the center of a rotating spiral galaxy, with wavelengths of 644, 656 and 668 nm. *Infer* the total mass of the galaxy, if $r=10^{12}$ m.

A) $M_{galaxy}=4.515 \times 10^{35}$ kg

B) $M_{galaxy}=6.10 \times 10^{23}$ kg

C) $M_{galaxy}=2.76 \times 10^{87}$ kg

D) $M_{galaxy}=8.16 \times 10^{58}$ kg

E) NOTA

Two identical 5 kg masses are separated by 4 m. If their gravitational PE=-Gm_1m_2/r, what is their escape velocity? ($G=6.67\times10^{-11}$ N/kg^2-m^2)

A) About 10 m/s

B) About 10 cm/s

C) About 1 cm/s

D) About 0.01 mm/s

E) >10 m/s or <0.001 mm/s

T=0: First, we use the orbital period of our planet (take earth) to measure one typical star: $mv_E^2/r_E=GmM_{Sun}/r_E^2$. The mass of the Earth m cancels, r_E=150.23e9 m; from knowing that it takes one year to orbit a distance $2\pi r_E$, $v_E=2\pi r_E/3.154e+7$ seconds=30e3 m/s, so $M_{Sun}=1.989 \times 10^{30}$ kg. We multiply this by the total number of 'Suns' in a typical galaxy (1e11), to get the 'visible' mass of the galaxy as 1.989e41 kg.

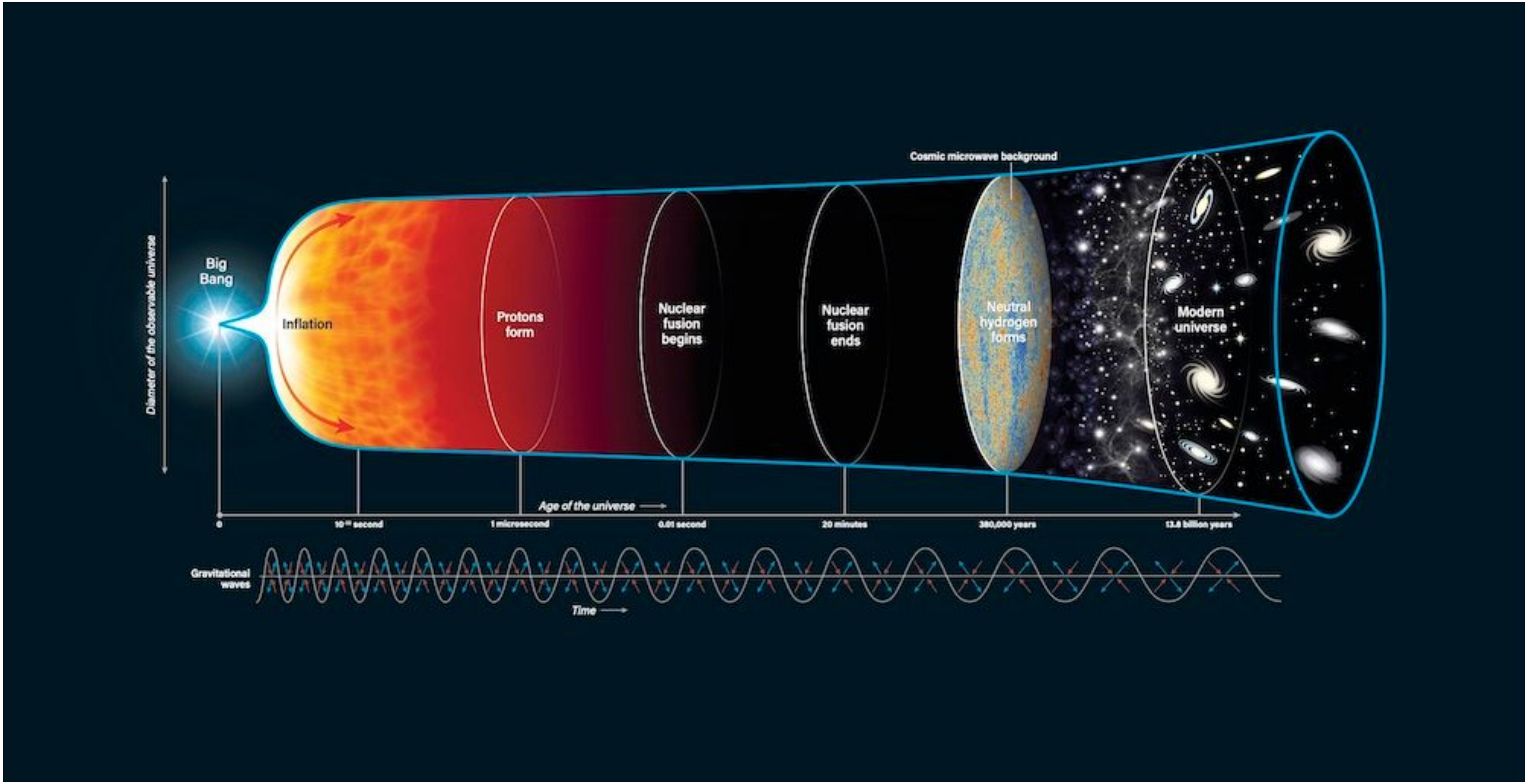
The typical distance between nearest 'big' galaxies (Andromeda to Milky Way, e.g.) is 0.89 Mpc (one Mpc=3.086e22 m); the size of the visible Universe (not the 'true' Universe) is about 28,520 Mpc. Let's take two galaxies that are separated by 16 Mpc (the size of our local 'supercluster'). We'll take a Hubble constant of 80 km/s/Mpc, so after 5 billion years (5e9*3.154e7=1.577e17 seconds), the two galaxies have separated through an additional
16 Mpc*1.577e17 s*80000m/s/Mpc further away, or 6.54 Mpc. If we wait another 5 billion years, the two galaxies are now (16+6.54)*1.577e17*80000=9.21 Mpc additionally separated.

In reality, the separation, since it is exponential (sorta like a random virus spreading), the increase is much faster than this.

At what distance are the two galaxies separating at the velocity of light (3e8 m/s)?
3e8m/s/(80000m/s/Mpc)=375 Mpc!

What is ratio of PE between galaxies: $-Gm_1m_2/r$ to relative KE: $\frac{1}{2}m_1v_1^2$?
PE=6.67e-11*1.989e41*1.989e41/(16*3.086e22) vs. ½*1.989e41*(16*80e3)*(16*80e3)
PE<<KE => OPEN Universe!

(corrections: i) we only considered interaction of galaxy A with galaxy B; in principle, galaxy A interacts with all other galaxies in the Universe, so |PE| increases, ii) we ignored dark matter, which will increase PE relative to KE by about a factor of 5



Cosmic microwave background
Diameter of the observable universe
Big Bang
Inflation
Protons form
Nuclear fusion begins
Nuclear fusion ends
Neutral hydrogen forms
Modern universe
Age of the universe
0
10 second
1 microsecond
0.01 second
20 minutes
380,000 years
13.8 billion years
Gravitational waves
Time

Stuff you can’t see that permeates all of space:

- Big Bang Photons (CMB, 400/cc)
- Big Bang Neutrinos (330/cc)
- Other neutrinos (40 billion/cm^2)
- Dark Energy
- Dark Matter
- Higgs Field
- Occasional CR (1/m^2/sec)

Between the idea   And the reality   Between the motion   And the act   Falls the Shadow

Between the conception   And the creation   Between the emotion   And the response   Falls the Shadow

Between the desire   And the spasm   Between the potency   And the existence   Between the essence   And the descent   Falls the Shadow

This is the way the world ends
This is the way the world ends
This is the way the world ends
Not with a bang but a whimper. -T.S. Eliot, 1915