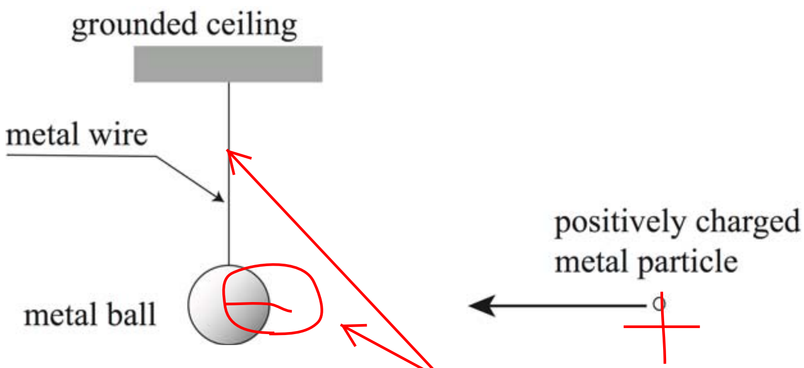
The next two questions pertain to the situation described below.

A (light) metal ball hangs from the ceiling with a flexible metal wire. Assume that the ceiling is grounded.



1) A small, positively charged metal particle gently approaches the metal ball from the right as shown in the figure above.

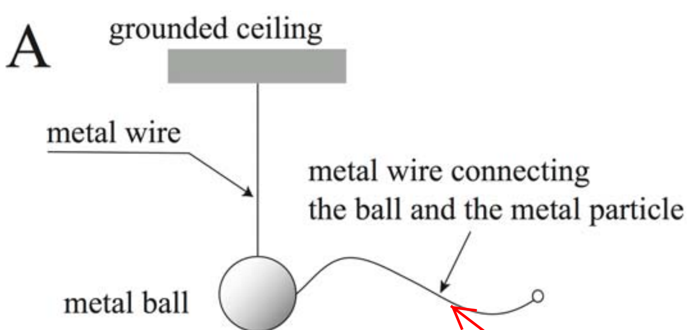
What happens to the metal ball? Choose the right description.

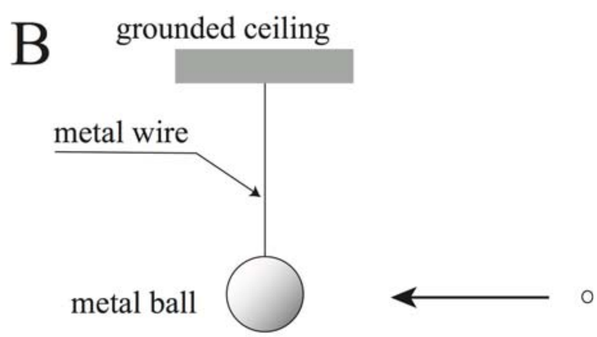
a. The metal ball moves to the left.
b. The metal ball does not move at all.
c. The metal ball moves to the right.

electrostatic induction
Charges with the same sign wish to avoid each other as much as possible.

+ can run away to the earth

2) The positively charged metal particle is stopped, and is connected to the metal ball with a conducting wire (A below). After removing the wire, the metal particle again moves toward the metal ball (B below).





What happens to the metal ball? Choose the right description.

a. The metal ball moves to the right.
b. The metal ball moves to the left.
c. The metal ball does not move at all.

This connection allows the positive charge to escape to the ground. There will be no charge after this connection.

The next two questions pertain to the situation described below.

On identical glass stands are two identical, small metal balls with charge Q and $-2Q$ as shown in the figure.

The distance between the two stands is $2r$.

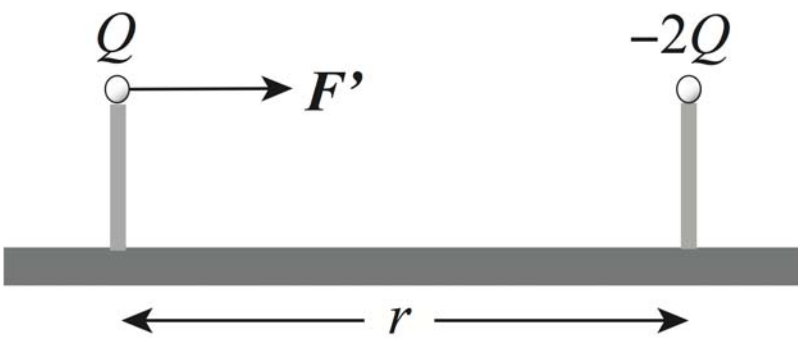
The magnitude of the force on the left charge is $|\boldsymbol{F}|$.

Coulomb's law
F = k QQ'/R^2

The stands are moved so that the distance between the two balls is halved to r . The magnitude of the force acting on the left charge becomes $|\boldsymbol{F}'|$.

3) What is the ratio of these force magnitudes?

Distance halved R -> R/2
F -> 4F = F'



a. $|\boldsymbol{F}|/|\boldsymbol{F}'| = 1/2$

b. $|\boldsymbol{F}|/|\boldsymbol{F}'| = 1$

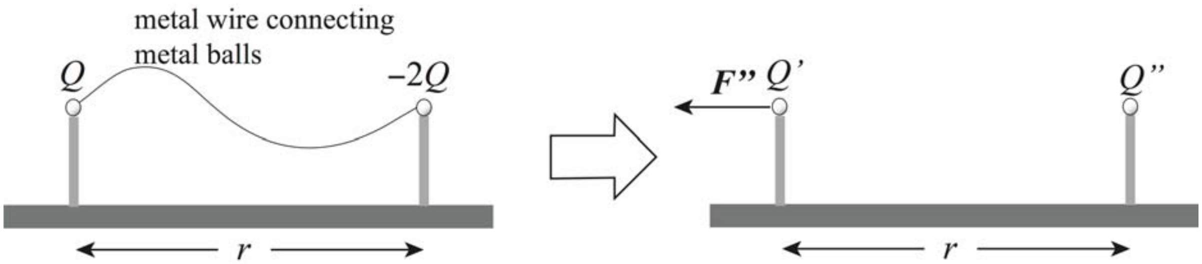
c. $|\boldsymbol{F}|/|\boldsymbol{F}'| = 1/8$

d. $|\boldsymbol{F}|/|\boldsymbol{F}'| = 1/4$

e. $|\boldsymbol{F}|/|\boldsymbol{F}'| = 1/6$

4) Now, an uncharged and insulated metal wire connects these two metal balls (Figure below left). Again these two balls are isolated as illustrated in Figure right.

The magnitude of the force acting on the left charge after this procedures is $|\boldsymbol{F}''|$.



What is the ratio of the magnitude of this force and that $|\boldsymbol{F}'|$ (as in the preceding question) before connecting the balls?

Conservation of the total charge + symmetry

a. $|\boldsymbol{F}'|/|\boldsymbol{F}''| = 8$
b. $|\boldsymbol{F}'|/|\boldsymbol{F}''| = 6$
c. $|\boldsymbol{F}'|/|\boldsymbol{F}''| = 1$
d. $|\boldsymbol{F}'|/|\boldsymbol{F}''| = 4$
e. $|\boldsymbol{F}'|/|\boldsymbol{F}''| = 2$

```
Q + (-2Q) = Q' + Q"
Q' = Q"
Therefore, Q' = Q" = -Q/2,
F'= kQ(2Q)/(R/2)^2
F" = k(Q/2)^2/(R/2)^2 = F'/8
```

The next two questions pertain to the situation described below.

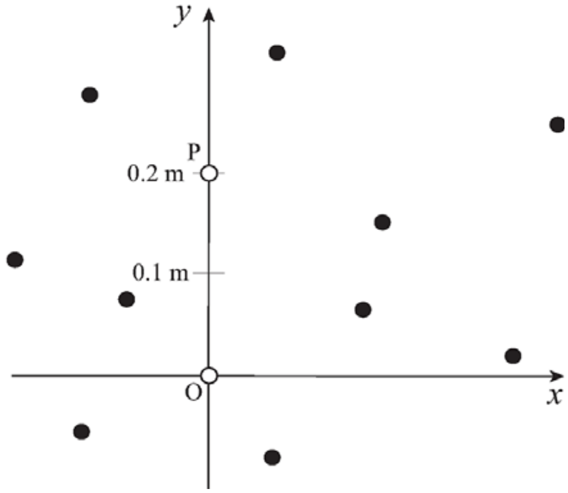
On the *xy*-plane multiple point charges (denoted by bullets) are distributed as shown in the figure.

These charges are fixed to the space throughout the following questions.

superposition principle

U = QV
electric potential energy U
electric potential V

W = Ufinal - Uinitial



Consider the following statements about the work **you do** in order to move a charge of 6 μC from infinity (very far away):

- To the origin O: $W_O = +21$ J.
- To the point P: $W_P = +20$ J.

5) How much work do **you** do to bring a charge of $q = -12\ \mu$C from infinity to the origin, O?

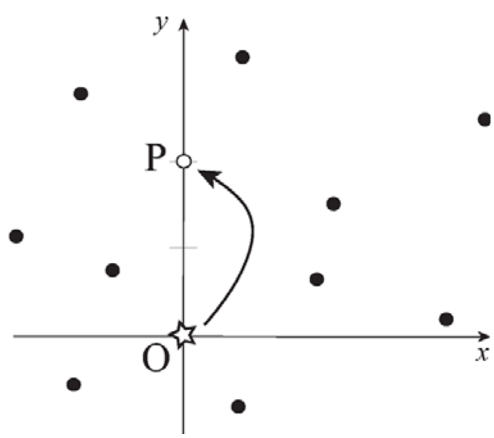
They mean Vo = 21/6mu and
Vp = 20/6mu (volts)

a. $W = -42$J
b. $W = 21$J
c. $W = 42$ J

```
W = QVo = (-12mu) x (21/6mu) = -42 J
```

6) How much work must **you** do to move $q = -12\ \mu$C from the origin to point P?

```
W = Q(Vfinal - Vinitial) = Q(Vp - Vo)
  = (-12mu) x (20/6mu - 21/6mu) = + 2 J
```



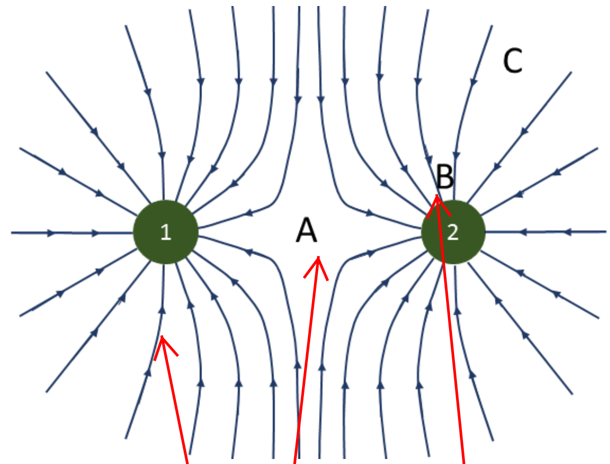
a. $W = 0$ J
b. $W = 2$ J
c. $W = -40$ J
d. $W = 40$ J
e. $W = -2$ J

The next two questions pertain to the situation described below.

Two charges (labeled **1** and **2**) create an electric field sketched in the figure.

Q/epsilon0 lines come out of + charge +Q (and sucked by a negative charge.

Thus, `line density' denotes the field intensity.



Both in

lowest density

highest density

7) What is the sign of the the two charges?

a. **1** is negative, **2** is negative
b. **1** is positive, **2** is positive
c. **1** is positive, **2** is negative
d. The **signs** of the charges cannot be determined.
e. **1** is negative, **2** is positive

8) Compare the relative magnitudes of the electric field at the three points in space labeled A, B and C.

a. A > B > C
b. C > B = A
c. A > C > B
d. C > B > A
e. B > C > A

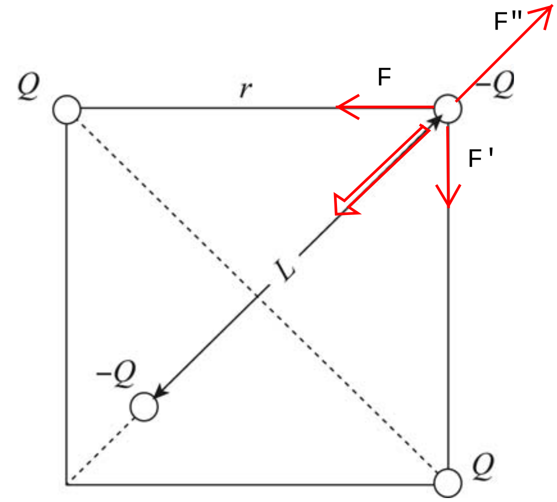
superposition principle

9) On the three corners of a square of edge r are two positive charges Q and one negative charge $-Q$ as illustrated.

We wish to place a second negative charge, $-Q$, along the diagonal distance L from the first negative charge so that there is no force on the negative charge at the upper right corner.

Find r/L.

First, sketch the forces on the charge due to individual charges.



a. $r/L = 1$

b. $r/L = 2^{1/8}$

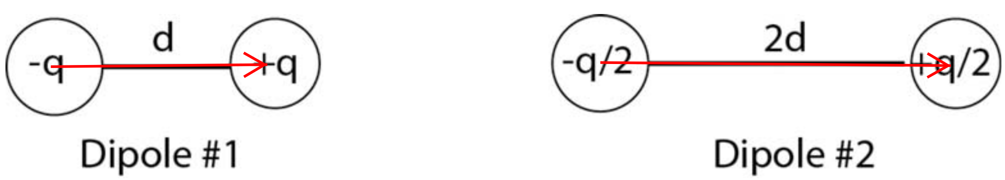
c. $r/L = 2^{-1/8}$

d. $r/L = 2^{1/2}$

e. $r/L = 2^{1/4}$

```
F = F' = kQ^2/r^2 (magnitude)
Therefore, their vector sum (thick red arrow) has a magnitude
      sqrt{2}kQ^2/r^2,
which must be equal to
      kQ^2/L^2.
Hence, sqrt{2}/r^2 = 1/L^2, or
      L = r/2^{1/4} -> r/L = 2^{1/4}.
```

10) Compare the magnitude of the dipole moment, p_1, of Dipole #1 to the magnitude of the dipole moment, p_2, of Dipole #2.



p = qd

a. $p_1 = p_2$

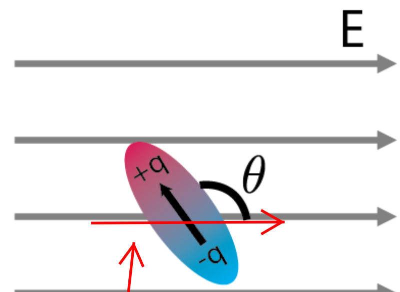
b. $p_1 > p_2$

c. $p_1 < p_2$

11) Consider an electric dipole in a uniform electric field of magnitude E = 20 N/C.

The dipole has dipole moment with magnitude $|\boldsymbol{p}|$ = 2 Cm.

It is placed at an angle $\theta = 120^{\circ}$ with respect to the electric field as shown in the figure.



The dipole is released and allowed to rotate in the electric field until it comes to rest in the lowest-energy direction.

What is the change in potential energy, ΔU, stored by the dipole between the initial and final configurations?

If the energy 0 is the perp direction
U = - dE cos theta

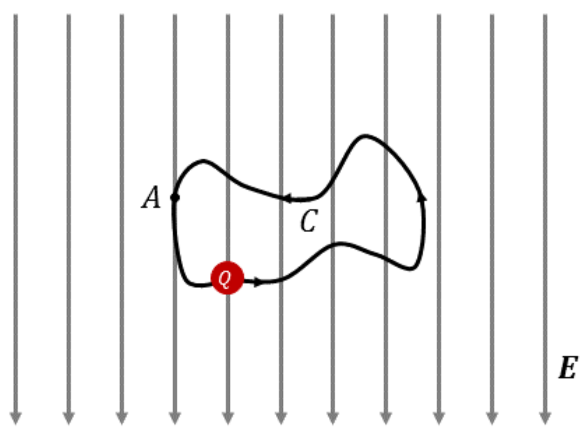
a. $\Delta U = -60$ J
b. $\Delta U = 30$ J
c. $\Delta U = 40$ J
d. $\Delta U = -40$ J
e. $\Delta U = 0$ J

```
D U = Ufinal - Uinitial
    = dE(cos(theta_init) - cos(theta_final))
    = 2 x 20 x(cos 120 -cos 0)
    = 40 x (-1/2 - 1)
    = -60 J
```

The lowest energy direction.

12) What work, W, do you have to supply to drag charge Q from point A along the curve C back to the same point A in the uniform electric field E?

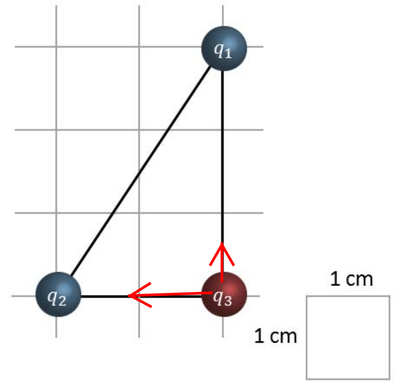
The potential energy is the same if the location is the same.



a. $W < 0$
b. $W = 0$
c. $W > 0$

superposition principle

13) Consider the following configuration of three point charges:



$q_1 = -12\ \mu C$

$q_2 = -8\ \mu C$

$q_3 = 3\ \mu C$

Sketch the fields due to individual charges

E = kQ/R^2

arranged in a right triangle as shown in the figure.

The point charges q_1 and q_3 are both on the y-axis of the coordinate system.

Calculate the **magnitude** of the electric field, $|E_{tot}|$, at the position of charge q_3 due to charge q_1 and q_2.

```
due to q1 = 9x10^9 x 12mu/(3x10^{-2})^2
due to q2 = 9x10^9 x 8mu/(2x10^{-2})^2

Etot = sqrt(E1^2 + E2^2)
     = 9x10^7 x sqrt{(12/9)^2 + (8/4)^2}
     = 21.6 x 10^8  J/C or V/m
```

a. $|E_{tot}| = 3 \times 10^8$ V/m

b. $|E_{tot}| = 2.2 \times 10^8$ V/m

c. $|E_{tot}| = 3.8 \times 10^8$ V/m

d. $|E_{tot}| = 4.6 \times 10^8$ V/m

e. $|E_{tot}| = 0$ V/m

superposition principle

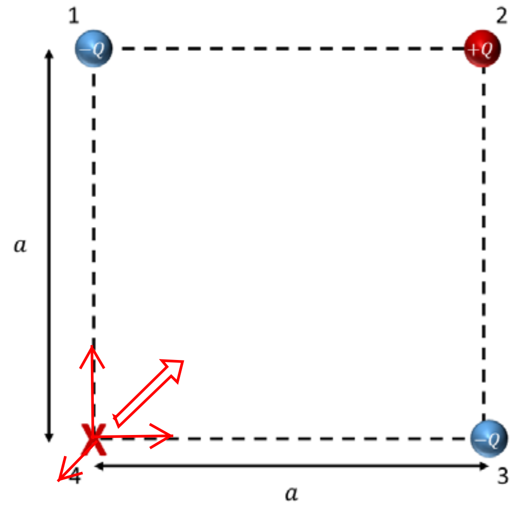
14) Three point charges are placed at the corners of a square as shown in the diagram.

Each charge has magnitude Q.

The edge length of the square is a.

The charges at corners 1 and 3 are **negative**.

The charge at corner 2 is **positive**.



What is the magnitude of the electric field, $|\vec{E}|$, at the red X?

Sketch the fields due to individual charges
E = kQ/R^2
Direction along the line connecting the charge and the point

a. $|\vec{E}| = (2\sqrt{2}+1)kQ/(2a^2)$

b. $|\vec{E}| = 3\sqrt{2}kQ/a^2$

c. $|\vec{E}| = (2\sqrt{2}-1)kQ/(2a^2)$

d. $|\vec{E}| = \sqrt{2}kQ/(2a^2)$

e. $|\vec{E}| = 3kQ/(2a^2)$

```
due to 1 = kQ/a^2 = due to 3
their vector sum = sqrt{2}kQ/a^2
due to 2 = kQ/2a^2
Taking the directions into account,
the total magnitude reads
      sqrt{2}kQ/a^2 - kQ/2a^2
```

15) Consider the two charges shown in the figure.

What is the change in the potential energy of a particle of charge $+q$ that is brought from a distance $3R$ to a distance R from a particle of charge $Q = -5q$?

a. $U = 5kq^2/(3R^2)$

b. $U = -10kq^2/(3R)$

c. $U = 5kq^2/(3R)$

d. $U = -10kq^2/(4R^2)$

e. $U = -10kq^2/R$

Compare the initial and final potential energy stored in this charge system
W = Ufinal - Uinitial

```
Ufinal = -kqQ/R
Uinitial = -kqQ/3R
so
W = -kqQ/R + kqQ/3R = 2kqQ/3R
```

The next two questions pertain to the situation described below.

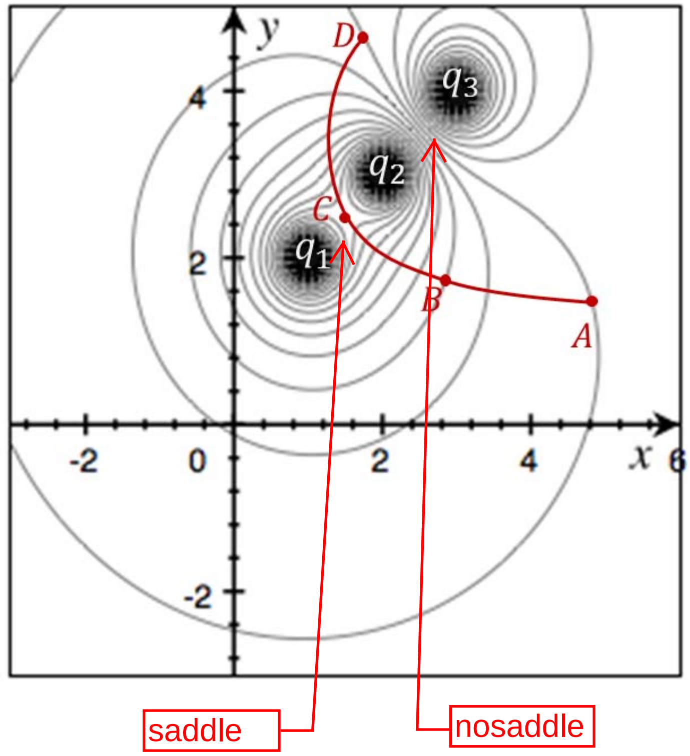
A map of equi-potential curves is shown in the figure.

The potential is created by three charges in the xy-plane: (q_1, q_2, and q_3).

Based on the map:

U = qV

Contour density = field intensity
Between two same sign charges
is a saddle point



16) Consider the following statements:

- Statement A: The charges q_1, q_2, and q_3 all have the same magnitude and sign.
- Statement B: The charges q_1 and q_2 have the same sign and q_3 has the opposite sign.
- Statement C: The charges q_2 and q_3 have the same sign and q_1 has the opposite sign.

Which of these statements is or are true?

a. None of these statements.
b. Statements A and B.
c. Statement B only.
d. Statement A only.
e. Statement C only.

17) The work, W, **you** must do to move the charge $-q$ along the path $ABCD$ is

contour describes the same potential.
U = qV

a. $W = 0$
b. $W < 0$
c. $W > 0$

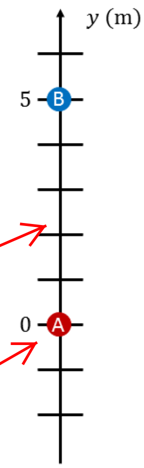
18)

Consider two charges:

$A = 125\ \mu\text{C}$ at $y = 0$.

$B = -25\ \mu\text{C}$ at $y = 5$ m.

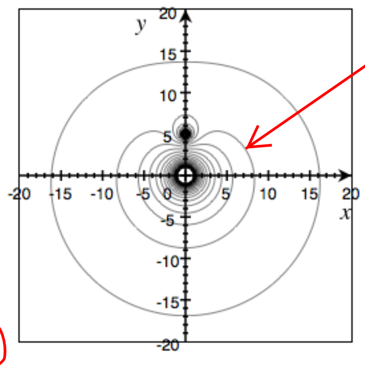
Contour density = field intensity
Between two same sign charges
is a saddle point



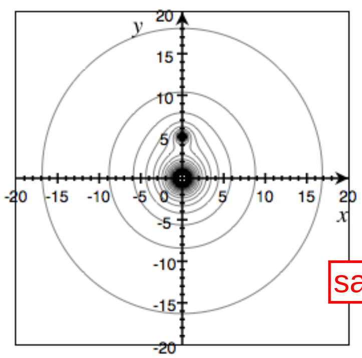
Which of the maps below most correctly describes the equipotential curves caused by this configuration of charges?

There must not be a saddle.

larger

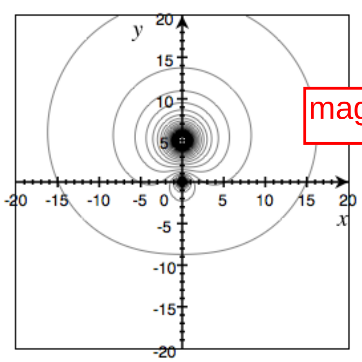


a.



saddle

b.



magnitudes wrong

c.

The next four questions pertain to the situation described below.

Four charges of equal magnitude are arranged on the coordinate system shown.

The charge values and locations are:

$Q_1 = -12\ \mu C$, located at (1 cm, 0 cm)

$Q_2 = -12\ \mu C$, located at (0 cm, 1 cm)

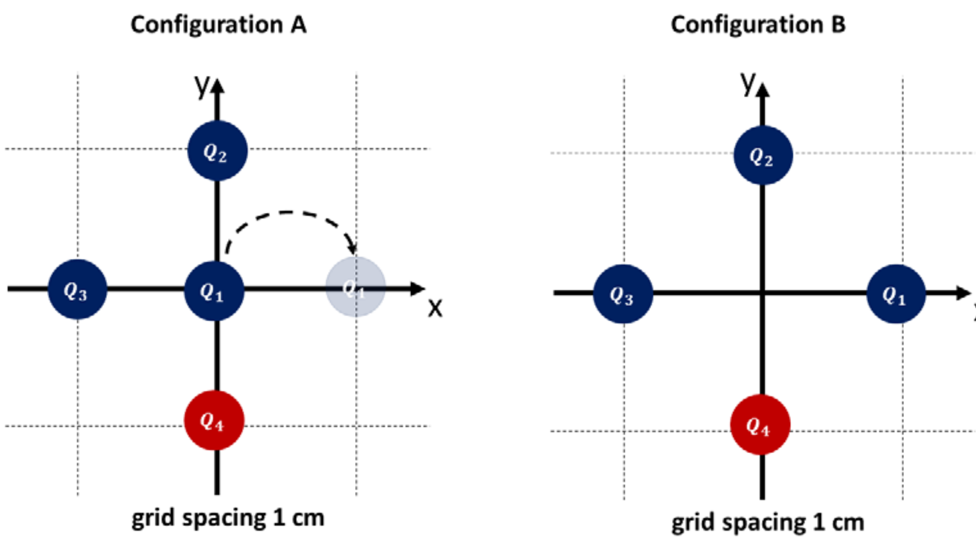
$Q_3 = -12\ \mu C$, located at (−1 cm, 0 cm)

$Q_4 = 12\ \mu C$, located at (0 cm, −1 cm)

superposition principle

W = Ufinal = Uinitial

19) What is the <u>absolute value</u> of the work **you** do moving Q_1 from the origin (Configuration A) to its final position at (1 cm, 0 cm) (Configuration B)?



Note: thanks to the symmetry Q2 and Q4 cancel each other, so you have only to consider the Q1Q3 pair.

W = Ufinal - Uinitial

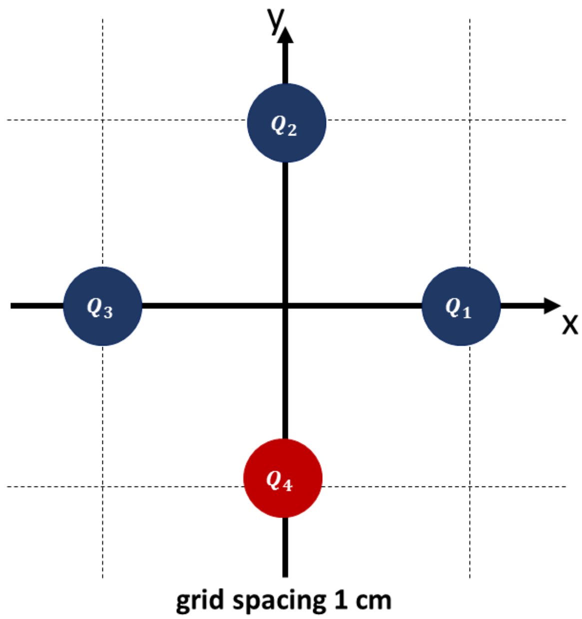
a. $|W_{you}| = 129$ J
b. $|W_{you}| = 26$ J
c. $|W_{you}| = 0$ J

```
Ufinal = kQ1Q3/2cm
Uinitial = kQ1Q3/1cm
so W = 9x10^9(12x10^{-6})^2(1/2x10^{-2} - 1/1x10^{-2})
     = -1296 x 10^{-1}/2 = -64.8 J.
```

20) The <u>sign</u> of the work **you** do moving Q_1 from the origin (Configuration A) to its final position at (1 cm, 0 cm) (Configuration B) is

a. neither.
b. positive.
c. negative.

21) Calculate the absolute value of the electrical potential at the origin due to the charges in the configuration shown. Remember: electric potential approaches zero (0) at infinity.



superposition principle

```
Q1 and Q3 matter.
V = 2kQ/r
  = 2 x 9x10^9 x (-12) x 10^{-6}/1x10^{-2}
  = -216 x 10^5 V
```

a. $|V(0, 0)| = 2.1576 \times 10^7$ V
b. $|V(0, 0)| = 4.3152 \times 10^7$ V
c. $|V(0, 0)| = 0$ V

22) The sign of the electrical potential at the origin for the configuration in the diagram is

a. negative.
b. positive.
c. zero.