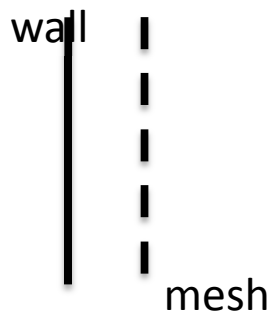


**Question 18:** Two strings of equal length (but different density) are joined together and set to vibrate in a standing wave. If the wave is as shown in the figure above, what is the ratio of the linear density of the string on the left to the linear density of the string on the right ( $\mu_L/\mu_R$ )?

- A) 1/4
- B) 1/2
- C) 1
- D) 2
- E) 4

**Question 20:** In an effort to control the noise in the Science One study room, James suggests that a wire mesh be installed on the walls to reduce the reflected noise. Some portion of the sound wave will be reflected off it, while the rest will pass through and get reflected off the wall. If James particularly wants to eliminate high-pitched giggling noises whose sound waves have wavelength 0.2m, how far should James install the mesh from the wall? (note: there is no phase shift for the reflections from the mesh or wall)



- A) 0.05m
- B) 0.1m
- C) 0.2m
- D) 0.4m
- E) 0.8m

**Question 21:** In a double-slit experiment, laser light is shone through a pair of slits, and a pattern of light and dark spots is observed on a screen. In which of the following situations will the spacing between the spots be the same as it was originally?

- A) Laser light with twice the wavelength is used, and distance between the slits is halved.
- B) Light with twice the frequency is used, and the distance between the slits is doubled.
- C) Laser light with twice the wavelength is used, and distance between the slits is doubled.
- D) Laser light with twice the amplitude is used, and the distance between the slits is doubled.

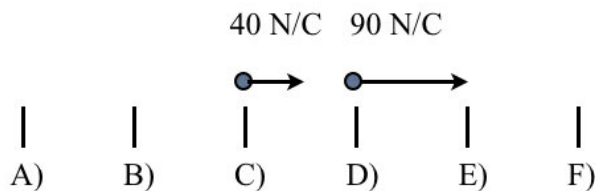
**Question 22:** In a double-slit experiment, laser light is shone through a pair of slits, and a pattern of light and dark spots is observed on a screen. If an identical experiment is performed in water, we expect that,

- A) The spots would get closer together.
- B) The spots would get further apart.
- C) The pattern would remain the same.

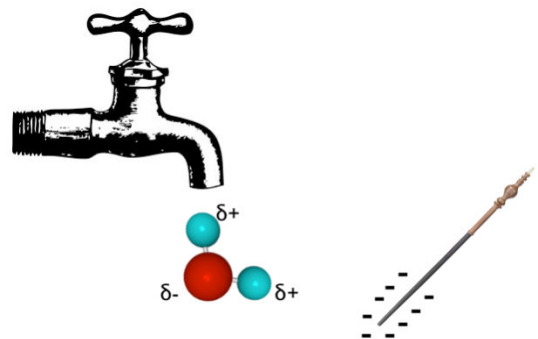
**Question 7:** The leaves of an electroscope are initially apart. A positively charged rod is brought near to the top of the electroscope and the leaves of the electroscope fall together.

- A) The electroscope must be negatively charged.
- B) The electroscope isn't charged at all.
- C) The electroscope must be positively charged.
- D) It's impossible to determine if it's positively or negatively charged.

**Question 8:** The electric field from a point charge is shown at two points along the x-axis. At what position does the charge rest?



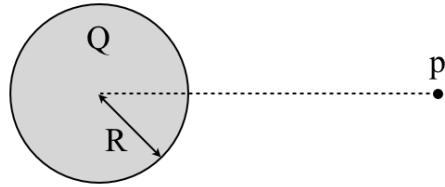
**Question 9:** A water molecule falls from a tap near a charged wand. What happens to the water molecule at the instant shown in the figure?



- A) It rotates counter-clockwise and moves towards the wand.
- B) It rotates clockwise and moves towards the wand.
- C) It rotates counter-clockwise and moves away from the wand.
- D) It rotates clockwise and moves away from the wand.
- E) It doesn't rotate and it moves away from the wand.
- F) It doesn't rotate and it moves towards the wand.

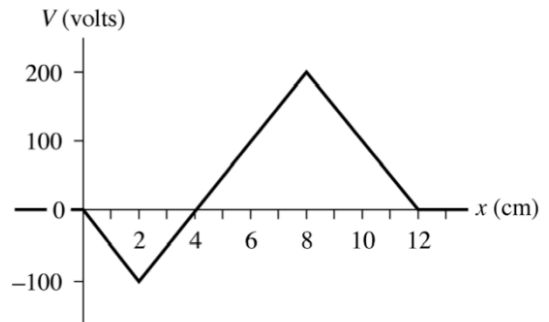
**Question 10:** The diagram below shows a charged spherical conductor of radius  $R$ . The radius of the sphere is doubled to  $2R$  and the charge is halved to  $Q/2$ . What is the ratio of the electric field at point  $p$  after the change compared with before the change  $E_{\text{after}}/E_{\text{before}}$ ?

- A) 2
- B) 1
- C) 1/2
- D) 1/4
- E) 1/8

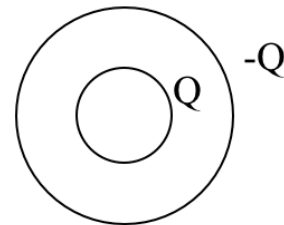


**Question 11:** The graph shows electric potential along the x-axis. A 20 nC particle is shot from the left ( $x < 0$ ) with  $10^{-6}$  J of kinetic energy. The particle will turn around at

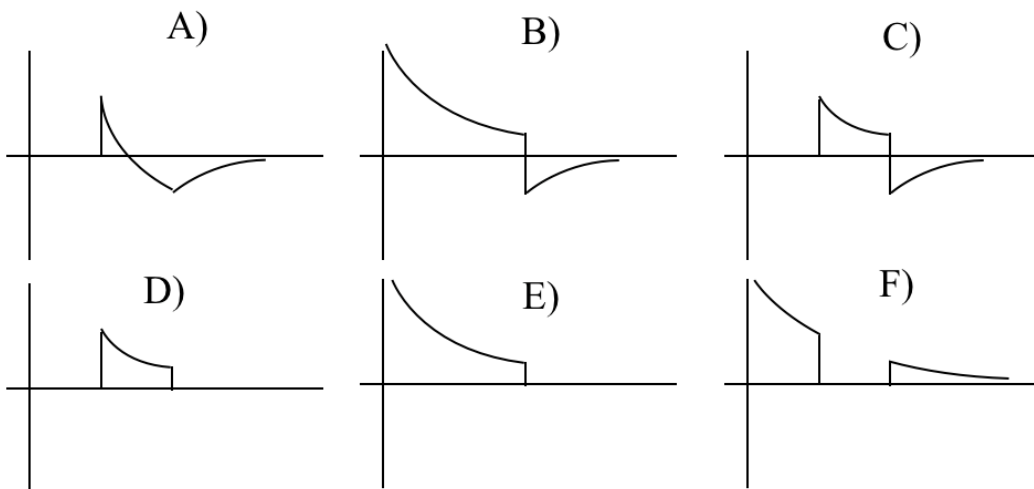
- A) 11 cm
- B) 10 cm
- C) 8 cm
- D) 5 cm
- E) 2 cm
- F) 1 cm
- G) no turning point



**Question 12:** The diagram to the right shows two thin charged spherical shells. The inner shell has a charge  $Q$  and the outer shell has a charge  $-Q$ .



Which plot below best describes the outward electric field as a function of radius in this situation?



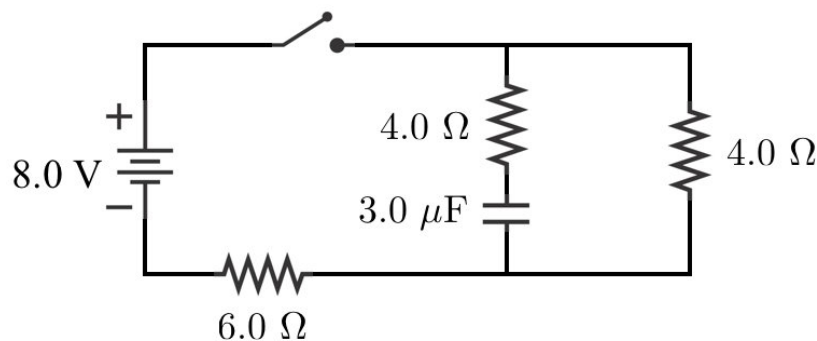
**Question 13:** In the Plinko! model of current, if the spacing between the atoms that make up the conducting material increases, what happens?

- A) Current increases because electron density increases
- B) Current decreases because electron density increases
- C) Current increases because the average time between collision increases
- D) Current increases because the average time between collision decreases
- E) Current decreases because the average time between collision increases
- F) Current decreases because the average time between collisions decreases

**Question 14:** You have a cylindrical resistor with resistance made out of silly putty. It starts with length  $L$  and radius  $r$ . You squish the resistor such that it has a new length  $L/2$  and a new radius. If the initial resistance is  $R_i$  and the final resistance is  $R_f$ , what is the ratio of the final resistance to the initial resistance  $R_f/R_i$ ?

- A) 1/8
- B) 1/4
- C) 1/2
- D) 1
- E) 2
- F) 4
- G) 8

**Question 15:** The circuit below starts with the switch open. The switch is then closed. What is the voltage across the 4 Ohm resistor *in series with the capacitor* i) the instant after the switch is closed and ii) after the switch has been closed for a long time?



	Instant after switch is closed:	A long time after the switch is closed:
A)	0 V	2.0 V
B)	0 V	3.2 V
C)	2.0 V	0 V
D)	2.0 V	3.2 V
E)	3.2 V	0 V
F)	3.2 V	2.0 V



**Question 16:** The picture above is a top view of two identical permanent magnets, one placed near a compass needle and the other floating freely on a pool of water (so that it is free to rotate). In the picture, which direction is north (i.e. towards the arctic)?

- A)  $\rightarrow$       B)  $\leftarrow$       C)  $\uparrow$       D)  $\downarrow$

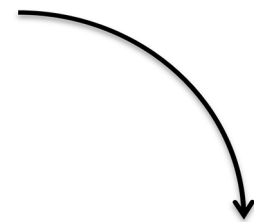
**Question 17:** In the picture below, which direction could the positive charge be moving in order to produce the magnetic field at point P shown by the arrow?

- A) Upwards on the page  
 B) Downwards on the page  
 C) To the right  
 D) To the left  
 E) Into the page  
 F) Out of the page



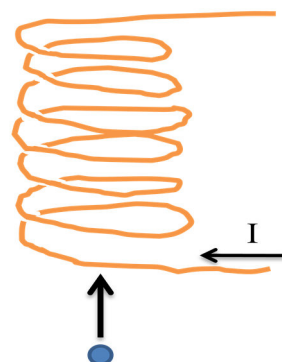
**Question 18:** The picture (below right) shows the trajectory of an electron, observed to move at a constant speed. This could be explained by

- A) A constant magnetic field pointing downward on the page  
 B) A constant magnetic field pointing into the page  
 C) A constant magnetic field pointing out of the page  
 D) A constant electric field pointing downward  
 E) A constant electric field pointing to the right



**Question 19:** A positively charged particle moves upward directly along the axis of a solenoid which carries a constant current. When the charge enters the magnetic field of the solenoid, it will

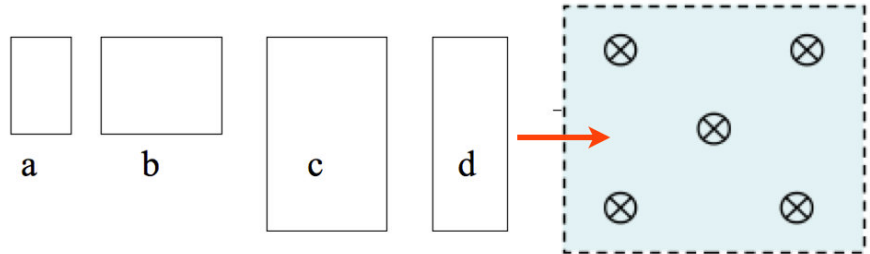
- A) Accelerate upward  
 B) Accelerate downward  
 C) Turn to the left  
 D) Turn to the right  
 E) Turn into the picture



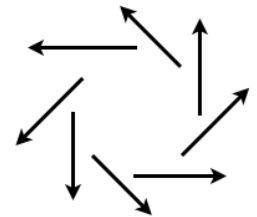
- F) Turn out of the picture
- G) Continue traveling at constant velocity.

**Question 20:** The figure below shows four wire loops. All four loops move through a region of a uniform B-field at the same constant velocity. Rank the four loops, according to the *maximum* emf induced as they move through the field.

- A)  $c > b = d > a$
- B)  $c = d > a = b$
- C)  $a = d > c = b$
- D)  $c > d > b > a$
- E)  $a = b = c = d$ .



**Question 21:** The diagram to the right shows an electric field configuration. What can you say about the cause of this field? Choose the most complete answer.

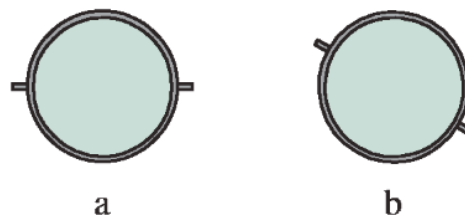


(Hint: what current would this electric field induce in a circular wire?)

- A) It's caused by an increasing magnetic field pointing into the page.
- B) It's caused by a decreasing magnetic field pointing into the page.
- C) It's caused by an increasing magnetic field pointing out of the page.
- D) It's caused by a decreasing magnetic field pointing out of the page.
- E) a) and d) are both right
- F) a) and c) are both right
- G) b) and c) are both right
- H) b) and d) are both right

**Question 22:** Four polarizers are stacked together, each with one of the two orientations shown. Which of the following combinations gives the greatest reduction in intensity for unpolarized incident light? The axis of polarization is in line with the two nubs on the polarizer.

- A) abab
- B) aabb
- C) abba
- D) baab



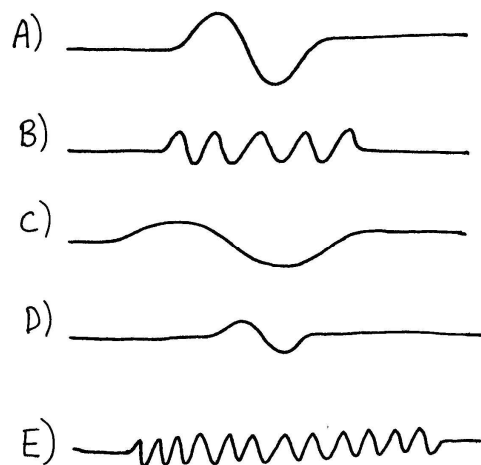
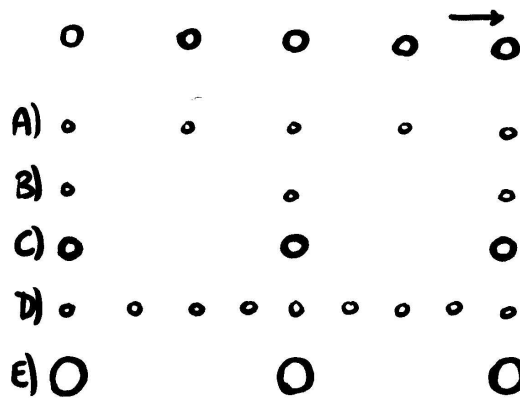




**Question 23:** A satellite travelling away from Earth emits radio waves uniformly in all directions with some total power  $P$ . In order that the amplitude of the radio waves reaching Earth remain the same later when the spacecraft is twice as far from Earth, the total power of the signal must be

- A)  $P$
- B)  $\sqrt{2}P$
- C)  $2P$
- D)  $4P$
- E)  $8P$

**Question 24:** The first picture below represents the photons in a beam of UV radiation. If size represents photon energy in the picture, which of the remaining pictures could represent a beam of blue visible light with the same power?

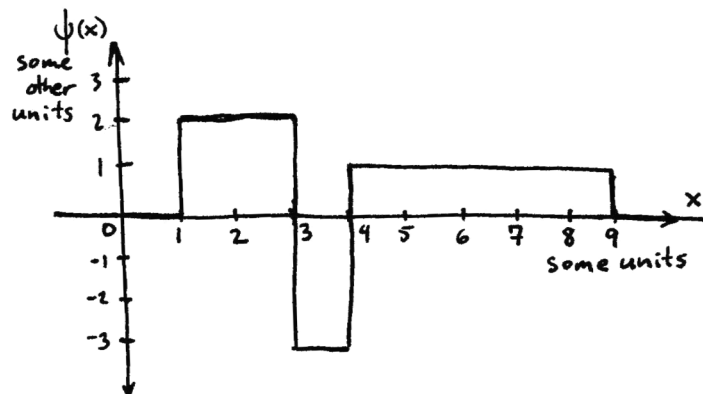


**Question 26:** The five functions above represent the real part of the wavefunctions for electrons moving to the right in a thin wire. After some time, which of these wavepackets will have moved the furthest?

- A) A
- B) B
- C) C
- D) D
- E) E

**Question 27:** At this later time, which of the wavefunctions in the previous question will have spread out the most relative to its initial size?

- A) A      B) B      C) C      D) D      E) E



**Question 28:** The graph above represents the wavefunction for an electron in a thin wire. In which region is the electron most likely to be found if a measurement of position is performed?

- A) between 1 and 3  
B) between 3 and 4  
C) between 4 and 9  
D) Finding the electron in each of these regions is equally likely.

**Question 29:** An electron is bound in a hydrogen atom in a state with some definite energy  $E$ . Which of the following is *not* true?

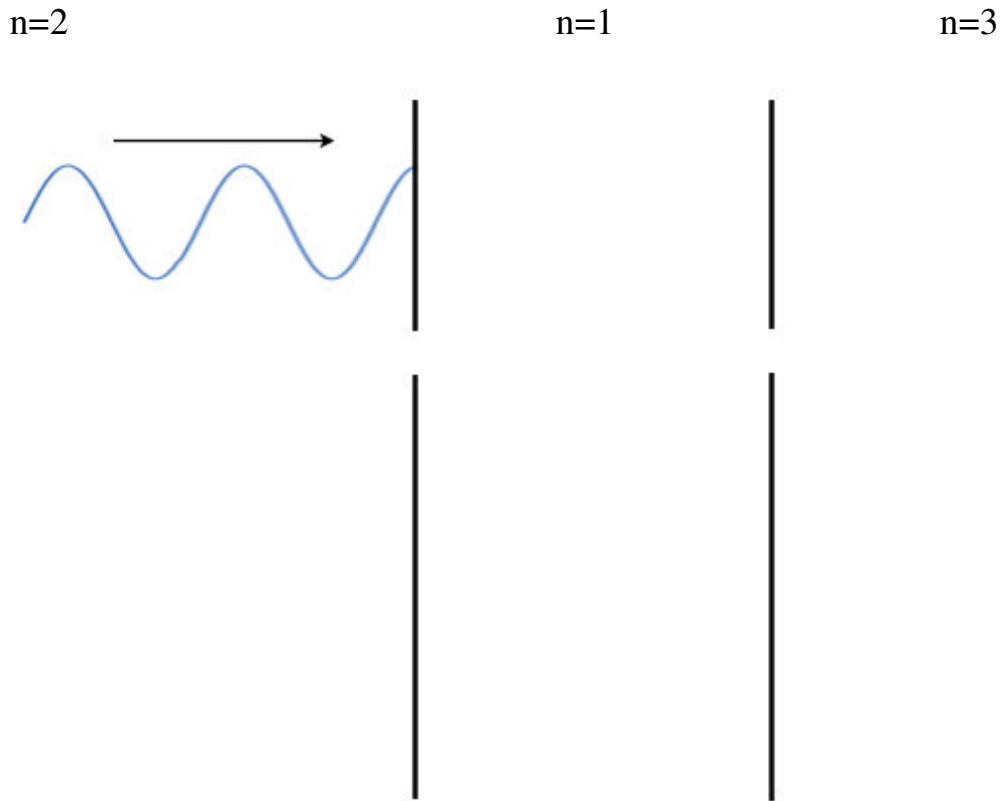
- A) There is a minimum possible value for  $E$   
B) The electron does not have a definite location  
C) The electron does not produce electromagnetic radiation because its velocity is zero  
D) The wavefunction for the electron oscillates with a definite frequency



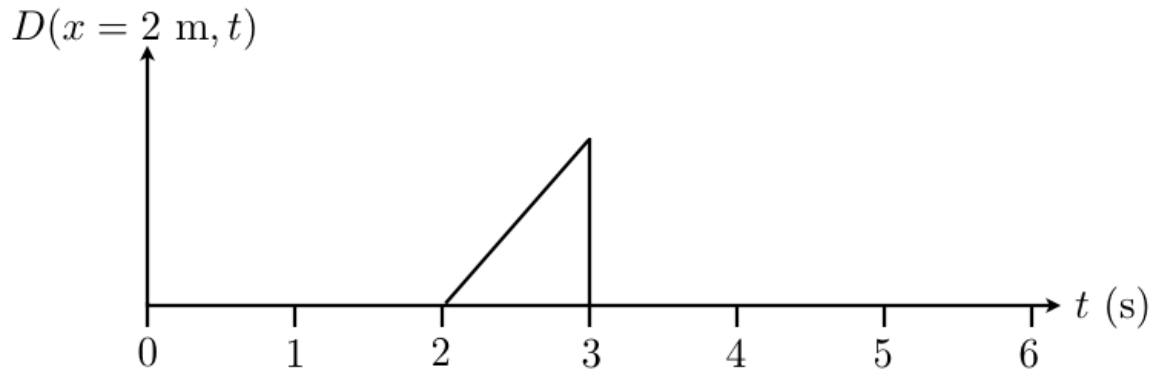
**Question 23:**

Light passes through a material that has two changes in the index of refraction. Draw the transmitted waves on the upper and the reflected waves on the lower part of the figure.

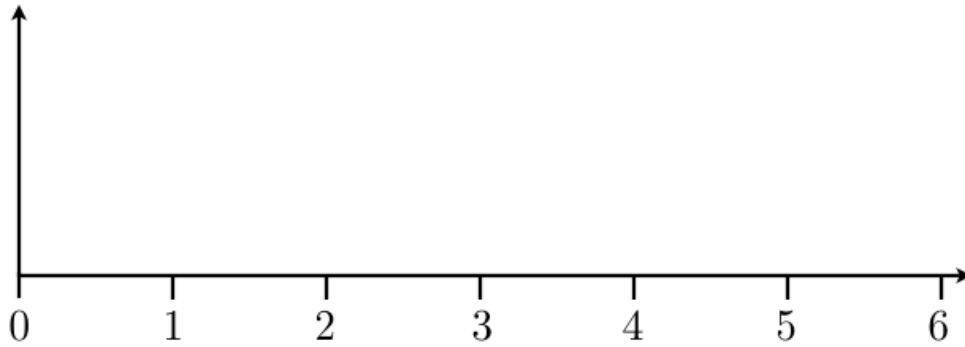
**(2 points)**



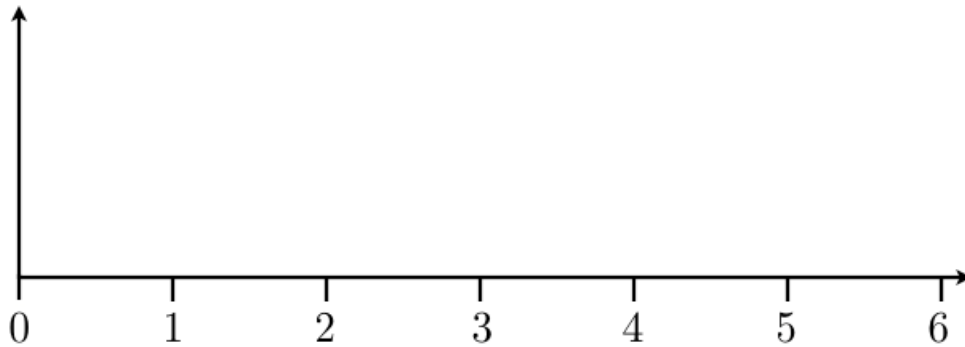
**Question 24:** Below is a history graph of a wave pulse travelling at 2 m/s to the right.  
**(2 points)**



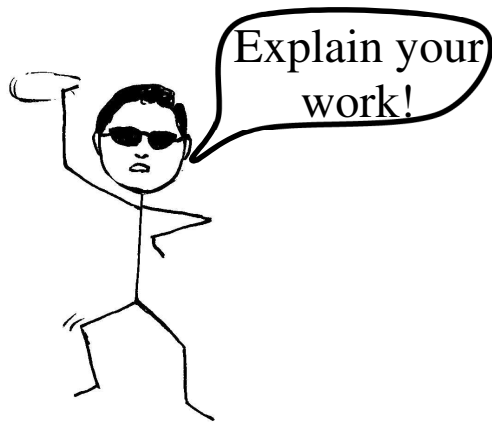
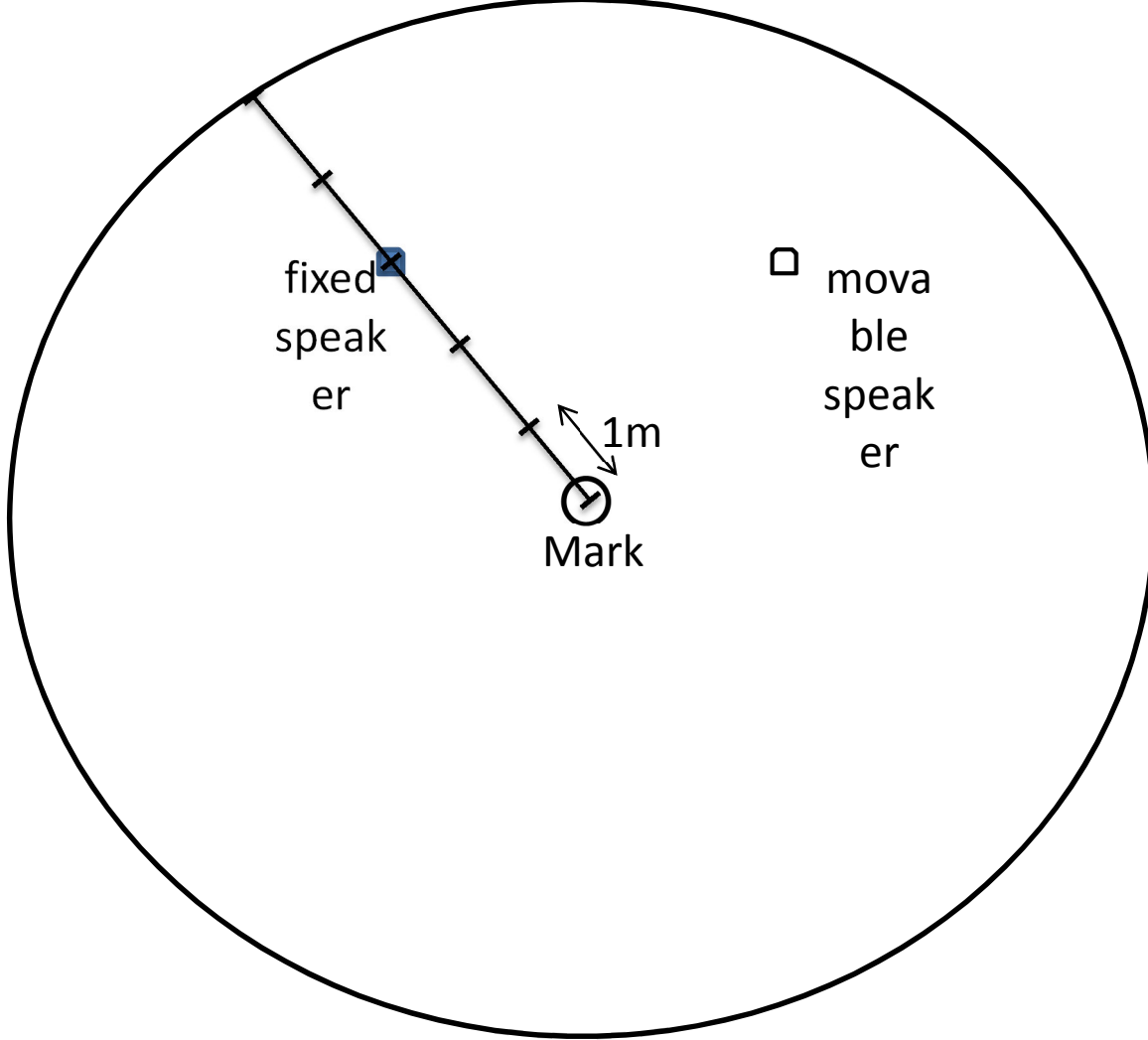
a) On the axes below, draw the snapshot graph for  $t = 3$  s.

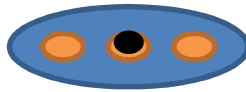


b) On the axes below, draw the history graph at  $x = 4$  m.

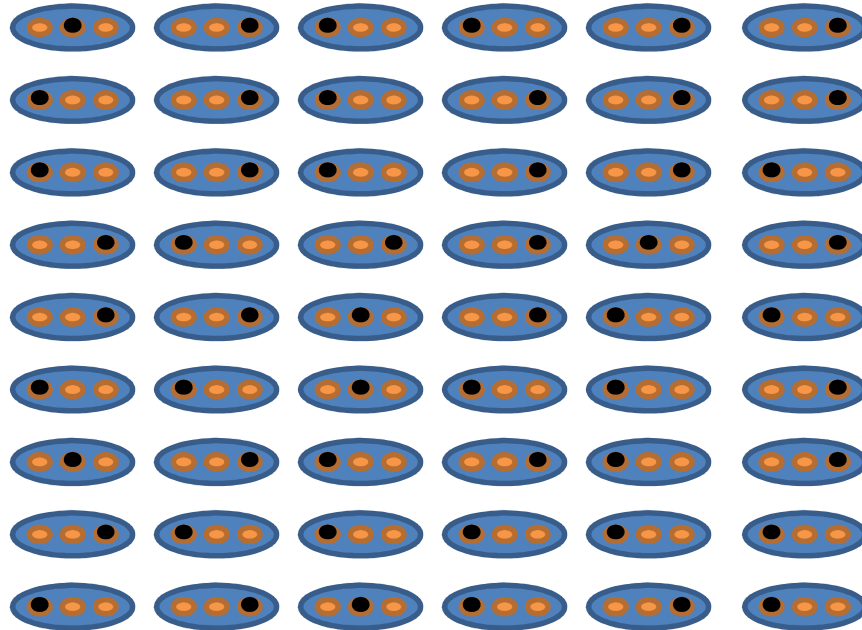


**Question 26:** Mark sits in the middle of a round room listening to Gangnam Style on repeat. Several days later, he begins to get tired of listening to the song. Unfortunately, there is no way to turn off the music. Fortunately, he finds that only one of the speakers is attached to the ground, and the other one can be moved anywhere he likes. On the picture below, indicate all the places where Mark can move the second speaker so that the most annoying part of the music (which has a frequency of 170Hz ) will be as quiet as possible at the location of his chair. Explain your answer below. (3 points)





**Question 31:** A microscopic quantum device is constructed which can trap an electron in three possible locations on its surface. Experimenters prepare a very large number of these devices, each with a single electron in the middle location. After some time, the position of the electron is measured in each device. The figure below shows a representative sample of the outcomes for these measurements



We can explain the results of the measurements above by saying that before the measurements, each electron was in the same state, a *quantum superposition* that we can represent as:

$$a \text{ (left)} + b \text{ (middle)} + c \text{ (right)}$$

Explain what this means, describe the significance of the numbers a, b, and c, and suggest values for the numbers a, b, and c that would be consistent with the measurement results above.





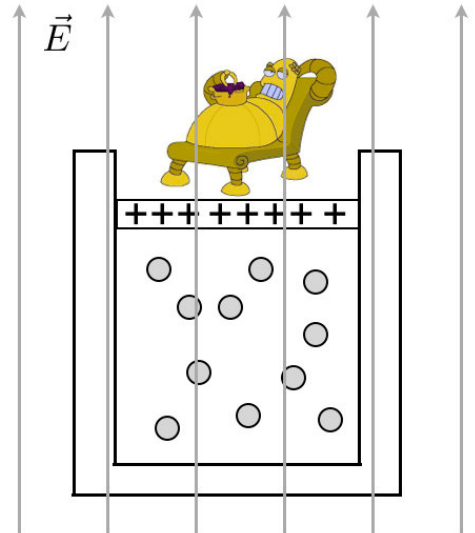
**Question 32:** Sketch a design for a simple electric motor and explain how it works.



**Question 34:**

Hedonism-bot will only sit on a platform suspended by pure oxygen. Hedonism-bot has one problem, though. When the temperature outside changes, the gas expands and contracts, which moves the platform up and down and drives Hedonism-bot crazy.

To fix the problem, Hedonism-bot has charged the platform with 1 Coulomb and installed a machine that can generate a uniform electric field of any strength that can point either up or down. When the temperature changes, the electric field will change, thus keeping the platform at a constant height.



If the electric field is initially zero and the temperature drops by 1 degree Kelvin, what will the final value of the electric field need to be?

Possibly useful info: When the temperature is 300 K the platform is 10 m above the bottom of the container. Hedonism-bot has a mass of 1000 kg, and the area of the platform is 5m<sup>2</sup>. The ambient air pressure is 100kPa.



**Question 35:**

A wire loop of mass  $M$ , area  $A$  and total resistance  $R$  rests at a distance  $x$  very far away from a bar magnet. At this distance we can assume that the magnetic field through the loop is essentially uniform, and the strength of the magnetic field is

$$B = \frac{\mu_0}{4\pi} \frac{2\mu}{x^3}$$

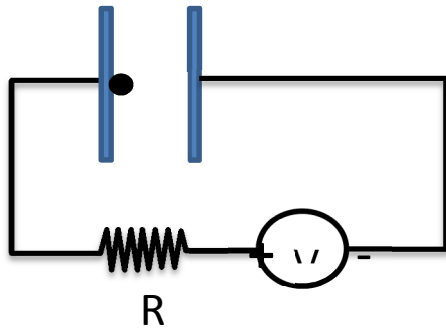
where  $\mu$  is the magnetic moment of the magnet (which is a constant). If the magnet is moved towards the loop at speed  $v$ , the loop is observed to move upward.

a) Explain why the loop moves upward.



b) Determine the acceleration of the loop. For this part, it may be helpful to know that the force between two aligned magnetic dipoles separated by a distance  $x$  is:

$$F = \frac{3\mu_0 \mu_1 \mu_2}{2\pi x^4}$$



**Question 36:** A particle with mass  $M$  and positive charge  $Q$  starts at one side of a capacitor. The capacitor has two parallel plates of area  $A$  separated by a distance  $d$ . We would like to make the particle move to the right with a trajectory

$$x(t) = d \log(1 + t/T)$$

where  $T$  is a constant and  $d$  is still the distance between the plates. To achieve this, what voltage  $V(t)$  do we need to apply at the voltage source?

## FORMULA SHEET

$$PV = nRT = Nk_b T \quad R = 8.31 \text{ J/(mol K)} \quad k = 1.38 \times 10^{-23} \text{ J/mol/K}$$
$$\Delta E = Q + W \quad \Delta E = n C_v \Delta T \quad C_v = 3/2R \text{ (ideal monotomic gas)}$$
$$W = -\int PdV$$

$$PV^\gamma = \text{constant} \quad \gamma = 1 + C_v/R$$

$$T = (2/3k_b)E_{\text{avg}}$$
$$P = (2/3)(N/V)E_{\text{avg}}$$

$$\mathbf{F} = m\mathbf{a}$$

$$F_r = -dU/dr \quad W = -\Delta U = -\int \mathbf{F} \cdot d\mathbf{r}$$

$$\mathbf{F} = q\mathbf{E} \quad U = qV$$

$$E_r = -dV/dr \quad \Delta V = -\int \mathbf{E} \cdot d\mathbf{r}$$

$$E = kq/r^2 \quad E = \eta/(2\epsilon_0) \quad E = 2kp/r^3 \quad p = qs \quad \text{Flux} = Q_{\text{enc}}/\epsilon_0$$

$$k = 9 \times 10^9 \text{ N m}^2/\text{C}^2 \quad \epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/(\text{N m}^2) \quad e = 1.6 \times 10^{-19} \text{ C} \quad \mu_0 = 4\pi \times 10^{-7} \text{ N/A}^2$$

$$\mathbf{F} = q\mathbf{E} + q \mathbf{v} \times \mathbf{B} \quad \mathbf{F} = I \mathbf{l} \times \mathbf{B} \quad \boldsymbol{\tau} = \boldsymbol{\mu} \times \mathbf{B} \quad \boldsymbol{\mu} = I \mathbf{A}$$

$$\mathbf{B} = \mu_0/(4\pi)q \mathbf{v} \times \mathbf{r} / r^3 \quad \mathbf{B} = \mu_0/(4\pi)I d\mathbf{s} \times \mathbf{r} / r^3 \quad B = (\mu_0 / 2 \pi) I/d \quad B = \mu_0 (N/L) I$$

$$V = IR \quad C = Q/V \quad P = IV$$

$$R = \rho LA \quad \sigma = n_e e^2 \tau / m = 1/\rho \quad v_d = e \tau E / m \quad I = e n_e A v_d$$

$$Q(t) = Q_0 \exp(-t/RC)$$

$$\epsilon = |d\Phi_m/dt| \quad \Phi = \mathbf{B} \cdot \mathbf{A} = BA \cos(\theta) \quad \oint \vec{E} \cdot d\vec{s} = -d\Phi_m/dt$$

$$\lambda f = c \quad I = I_0 \cos^2 \theta$$

$$E = hf \quad p = h/\lambda \quad \Delta x \Delta p = h/(4 \pi) \quad h = 6.6 \times 10^{-34} \text{ Js}$$