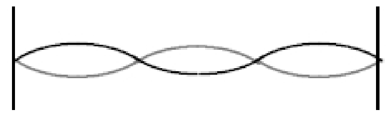
Chapter 9

Waves and Sound

AP Physics Multiple Choice Practice –Waves and Optics

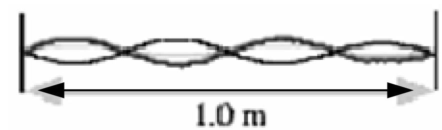
SECTION A – Waves and Sound

1. A string is firmly attached at both ends. When a frequency of 60 Hz is applied, the string vibrates in the standing wave pattern shown. Assume the tension in the string and its mass per unit length do not change. Which of the following frequencies could NOT also produce a standing wave pattern in the string?
   A) 30 Hz B) 40 Hz C) 80 Hz D) 180 Hz

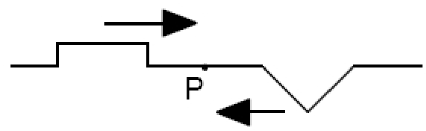


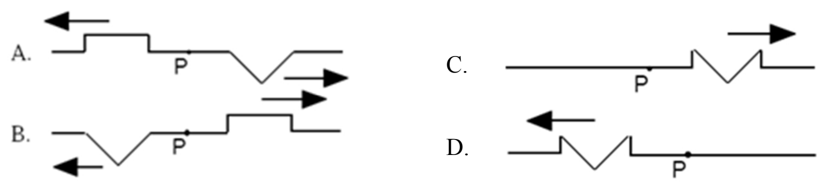
2. If the frequency of sound wave is doubled, the wavelength:
   A) halves and the speed remains unchanged.
   B) doubles and the speed remains unchanged.
   C) halves and the speed halves.
   D) doubles and the speed doubles.

3. The standing wave pattern diagrammed to the right is produced in a string fixed at both ends. The speed of waves in the string is 2 m/s. What is the frequency of the standing wave pattern?
   A) 0.25 Hz B) 1 Hz C) 2 Hz D) 4 Hz



4. Two waves pulses approach each other as seen in the figure. The wave pulses overlap at point P. Which diagram best represents the appearance of the wave pulses as they leave point P?





5. If the speed of sound in air is 340 m/s, the length of the organ pipe, open at both ends, that can resonate at the fundamental frequency of 136 Hz, would be:
   A) 0.40 m B) 0.80 m C) 1.25 m D) 2.5 m

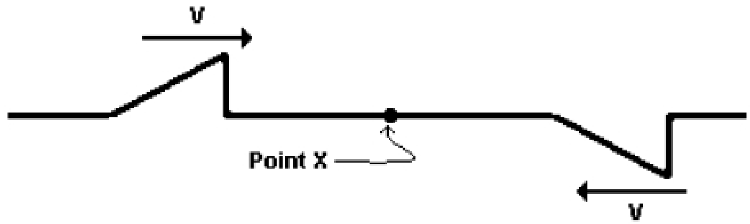
6. As sound travels from steel into air, both its speed and its:
   A) wavelength increase B) wavelength decrease C) frequency increase D) frequency remain unchanged

7. A pipe that is closed at one end and open at the other resonates at a fundamental frequency of 240 Hz. The next lowest/highest frequency it resonates at is most nearly.
   A) 80 Hz B) 120 Hz C) 480 Hz D) 720 Hz

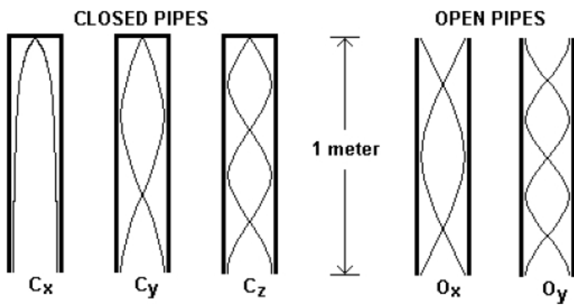
8. Assume that waves are propagating in a uniform medium. If the frequency of the wave source doubles then
   A) the wavelength of the waves halves. B) the wavelength of the waves doubles.
   C) the speed of the waves halves. D) the speed of the waves doubles.

9. Assume the speed of sound is 340 m/s. One stereo loudspeaker produces a sound with a wavelength of 0.68 meters while the other speaker produces sound with a wavelength of 0.65 m. What would be the resulting beat frequency?
   A) 3 Hz B) 23 Hz C) 511.5 Hz D) 11,333 Hz

10. The diagram shows two transverse pulses moving along a string. One pulse is moving to the right and the second is moving to the left. Both pulses reach point x at the same instant. What would be the resulting motion of point x as the two pulses pass each other?



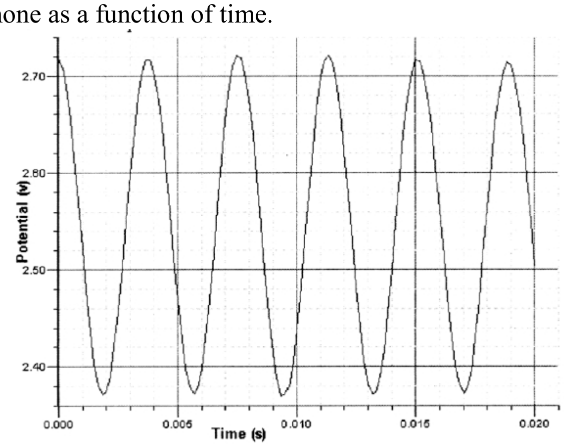
A) down, up, down
B) up then down
C) up, down, up
D) there would be no motion, the pulses cancel one another



11. **Multiple Correct.** The diagrams above represent 5 different standing sound waves set up inside of a set of organ pipes 1 m long Which of the following statements correctly relates the frequencies of the organ pipes shown? Select two answers.

A) C_y is twice the frequency of C_x. B) C_z is five times the frequency of C_x.
C) O_y is twice the frequency of O_x. D) O_x is twice the frequency of C_x.

Questions 12-13: The graph below was produced by a microphone in front of a tuning fork. It shows the voltage produced from the microphone as a function of time.



12. The frequency of the tuning fork is (approximately)
A) 0.004 s B) 0.020 s C) 50Hz D) 250 Hz

13. In order to calculate the speed of sound from the graph, you would also need to know
A) pitch B) wavelength C) frequency D) volume

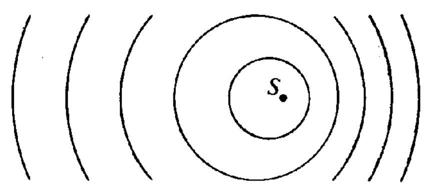
14. A tube is open at both ends with the air oscillating in the 4^{th} harmonic. How many displacement nodes are located within the tube?
A) 2 B) 3 C) 4 D) 5

15. A person vibrates the end of a string sending transverse waves down the string. If the person then doubles the rate at which he vibrates the string while maintaining the same tension , the speed of the waves
A) is unchanged while the wavelength is halved.
B) is unchanged while the wavelength is doubled.
C) doubles while the wavelength doubled.
D) doubles while the wavelength is halved.

16. A tube of length L_1 is open at both ends. A second tube of length L_2 is closed at one end and open at the other end. This second tube resonates at the same fundamental frequency as the first tube. What is the value of L_2 ?
A) $4L_1$ B) $2L_1$ C) L_1 D) ½ L_1

17. For a standing wave mode on a string fixed at both ends, adjacent antinodes are separated by a distance of 20 cm. Waves travel on this string at a speed of 1200 cm/s. At what frequency is the string vibrated to produce this standing wave?
(A) 120 *Hz* (B) 60 *Hz* (C) 40 *Hz* (D) 30 *Hz*

18. What would be the wavelength of the fundamental and first two overtones produced by an organ pipe of length L that is closed at one end and open at the other?
A) L, ½ L, ¼ L B) ½ L, ¼ L, 1/6 L C) 4L, 4/3 L, 4/5 L D) 4L, 2L, L

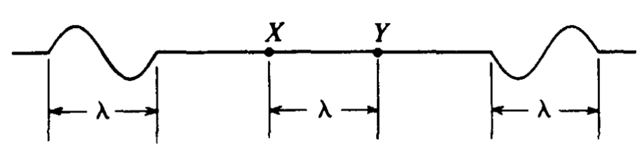


19. A small vibrating object S moves across the surface of a ripple tank producing the wave fronts shown above. The wave fronts move with speed v. The object is traveling in what direction and with what speed relative to the speed of the wave fronts produced?

Direction	Speed
(A) To the right	Equal to v
(B) To the right	Less than v
(C) To the left	Less than v
(D) To the left	Greater than v

20. A vibrating tuning fork sends sound waves into the air surrounding it. During the time in which the tuning fork makes one complete vibration, the emitted wave travels
(A) one wavelength
(B) about 340 meters
(C) a distance directly proportional to the square root of the air density
(D) a distance inversely proportional to the square root of the pressure

21. Two wave pulses, each of wavelength λ, are traveling toward each other along a rope as shown. When both pulses are in the region between points X and Y, which are a distance λ apart, the shape of the rope is



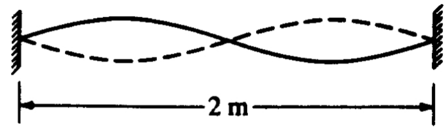
(A) 

(B) 

(C) 

(D) 

Questions 22-23



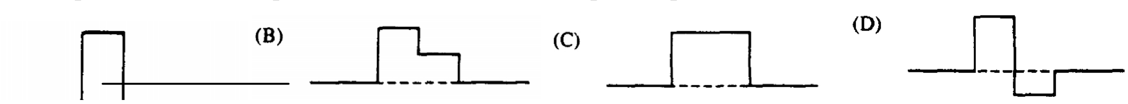
A standing wave of frequency 5 hertz is set up on a string 2 meters long with nodes at both ends and in the center, as shown above.

22. The speed at which waves propagate on the string is
    A) 0.4 m/s B) 2.5 m/s C) 5 m/s D) 10 m/s

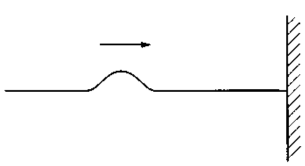
23. The fundamental frequency of vibration of the string is
    A) 1 Hz B) 2.5 Hz C) 5 Hz D) 10 Hz

24. **Multiple correct:** In the Doppler Effect for sound waves, factors that affect the frequency that the observer hears include which of the following? Select two answers.
    A) the loudness of the sound
    B) the speed of the source
    C) the speed of the observer
    D) the phase angle

25. The figure above shows two wave pulses that are approaching each other. Which of the following best shows the shape of the resultant pulse when the centers of the pulses, points P and Q coincide?

(A)


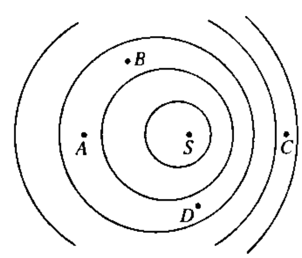
26. **Multiple Correct:** One end of a horizontal string is fixed to a wall. A transverse wave pulse is generated at the other end, moves toward the wall as shown and is reflected at wall. Properties of the reflected pulse include which of the following? Select two answers:



(A) It has a greater speed than that of the incident pulse.
(B) It has a greater amplitude than that of the incident pulse.
(C) It is on the opposite side of the string from the incident pulse.
(D) It has a smaller amplitude than that of the incident pulse.

27. A small vibrating object on the surface of a ripple tank is the source of waves of frequency 20 Hz and speed 60 cm/s. If the source *S* is moving to the right, as shown, with speed 20 cm/s, at which of the labeled points will the frequency measured by a stationary observer be greatest?

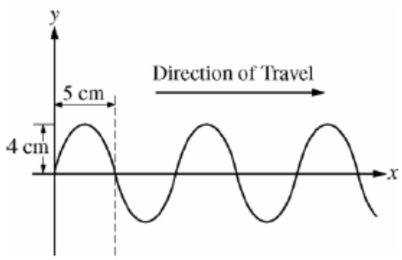
    (A) A (B) B (C) C (D) D



28. The frequencies of the first two overtones (second and third harmonics) of a vibrating string are f and 3f/2 .What is the fundamental frequency of this string?
    A) f/3 B) f/2 C) f D) 2f

29. **Multiple Correct:** Two fire trucks have sirens that emit waves of the same frequency. As the fire trucks approach a person, the person hears a higher frequency from truck X than from truck Y. Which of the following statements about truck X can be correctly inferred from this information? Select two answers.
   A) It is traveling faster than truck Y.
   B) It is closer to the person than truck Y.
   C) It is speeding up, and truck Y is slowing down.
   D) Its wavefronts are closer together than truck Y.

<u>Questions 30-31:</u>



The figure above shows a transverse wave traveling to the right at a particular instant of time. The period of the wave is 0.2 s.

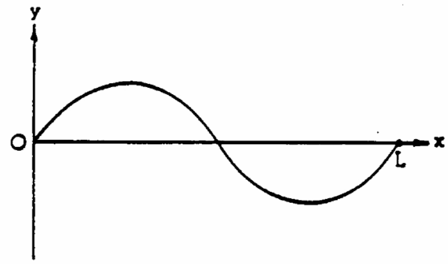
30. What is the amplitude of the wave?
   A) 4 cm B) 5 cm C) 8 cm D) 10 cm

31. What is the speed of the wave?
   A) 4 cm/s B) 25 cm/s C) 50 cm/s D) 100 cm/s

32. **Multiple Correct:** A standing wave pattern is created on a guitar string as a person tunes the guitar by changing the tension in the string. Which of the following properties of the waves on the string will change as a result of adjusting only the tension in the string? Select two answers.
   A) the speed of the traveling wave that creates the pattern
   B) the wavelength of the standing wave
   C) the frequency of the standing wave
   D) the amplitude of the standing wave

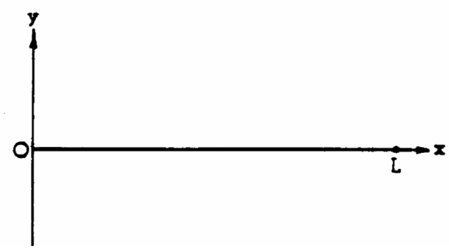
1980B4. In the graphs that follow, a curve is drawn in the first graph of each pair. For the other graph in each pair, sketch the curve showing the relationship between the quantities labeled on the axes. Your graph should be consistent with the first graph in the pair.

(c) y = Displacement of a String of Length L, Fixed at Both Ends, Vibrating at a Frequency f = 100 hertz



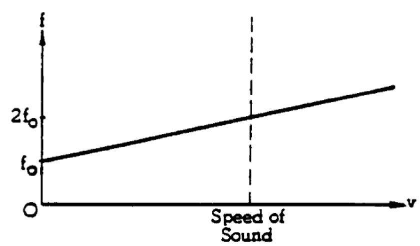
x = Distance from One End of the String

y = Displacement of a String of Length L, Fixed at Both Ends, Vibrating at a Frequency f = 150 hertz



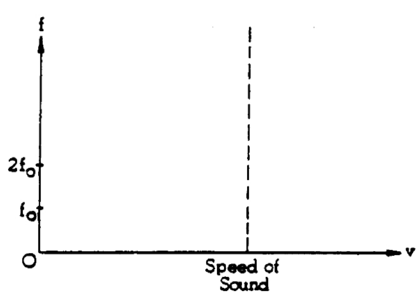
x = Distance from One End of the String

(d) f = Observed Frequency When Observer Moves Toward Stationary Source Emitting Sound of Frequency f_0



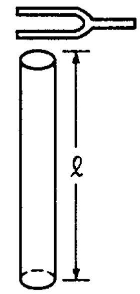
v = Speed of Moving Observer

f = Observed Frequency When Source Emitting Sound of Frequency f_0 Moves Toward Stationary Observer

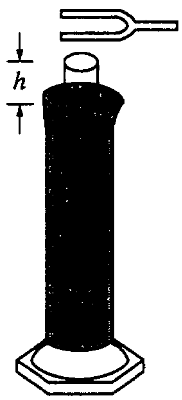


v = Speed of Moving Source

1995B6. A hollow tube of length L open at both ends as shown, is held in midair. A tuning fork with a frequency f_o vibrates at one end of the tube and causes the air in the tube to vibrate at its fundamental frequency. Express your answers in terms of L and f_o



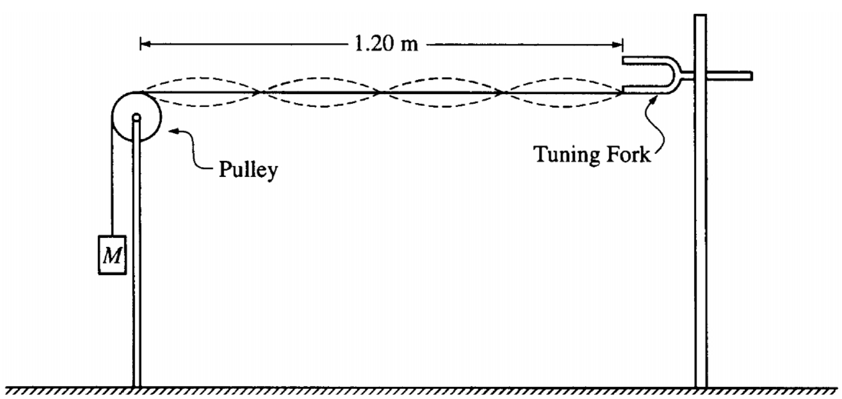
a. Determine the wavelength of the sound.
b. Determine the speed of sound in the air inside the tube.
c. Determine the next higher frequency at which this air column would resonate.



Note: Figure not drawn to scale.

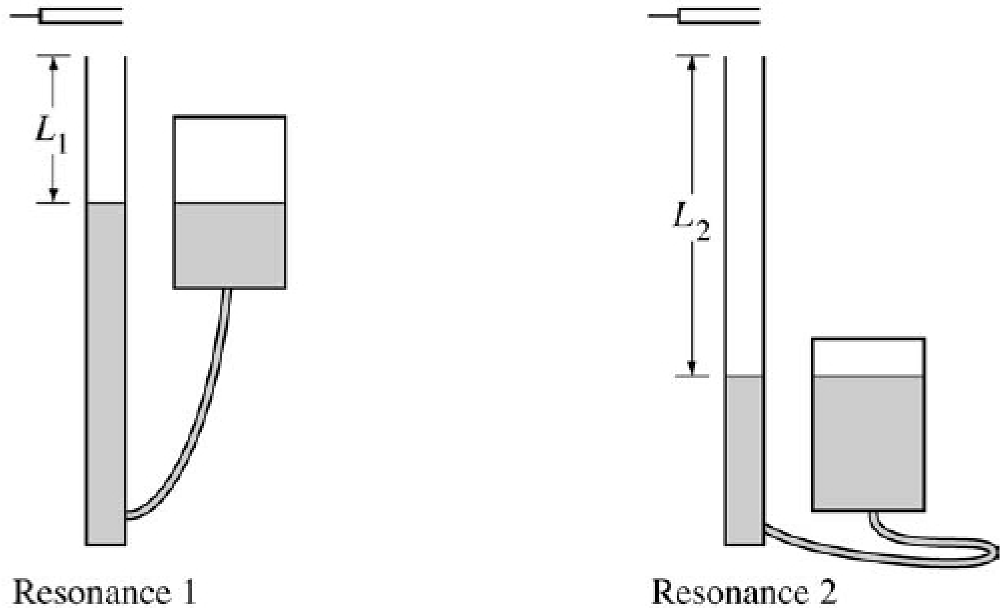
The tube is submerged in a large, graduated cylinder filled with water. The tube is slowly raised out of the water and the same tuning fork, vibrating with frequency f_o, is held a fixed distance from the top of the tube.

d. Determine the height h of the tube above the water when the air column resonates for the first time. Express your answer in terms of L.



1998B5. To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

a. Determine the wavelength of the standing wave.
b. Determine the speed of transverse waves along the string.
c. The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.
d. If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?



Note: Figure not drawn to scale.

B2004B3. A vibrating tuning fork is held above a column of air, as shown in the diagrams above. The reservoir is raised and lowered to change the water level, and thus the length of the column of air. The shortest length of air column that produces a resonance is $L_1 = 0.25$ m, and the next resonance is heard when the air column is $L_2 = 0.80$ m long. The speed of sound in air at 20° C is 343 m/s and the speed of sound in water is 1490 m/s.

(a) Calculate the wavelength of the standing sound wave produced by this tuning fork.
(b) Calculate the frequency of the tuning fork that produces the standing wave, assuming the air is at 20° C.
(c) Calculate the wavelength of the sound waves produced by this tuning fork in the water, given that the frequency in the water is the same as the frequency in air.
(d) The water level is lowered again until a third resonance is heard. Calculate the length L_3 of the air column that produces this third resonance.
(e) The student performing this experiment determines that the temperature of the room is actually slightly higher than 20° C. Is the calculation of the frequency in part (b) too high, too low, or still correct?

_____ Too high _____ Too low _____ Still correct Justify your answer.

AP Physics Multiple Choice Practice – Waves and Optics – ANSWERS

SECTION A – Waves and Sound

	Solution	Answer
1.	The given diagram is the 3rd harmonic at 60 Hz. That means the fundamental is 20Hz. The other possible standing waves should be multiples of 20	A
2.	Frequency and wavelength are inverses	A
3.	From diagram, wavelength = 0.5 m. Find the frequency with $v = f\lambda$	D
4.	After waves interfere they move along as if they never met	B
5.	For an open–open pipe the harmonic frequency is given by. $f_n = \dfrac{nv}{2L}$ with n=1	C
6.	When sound travels into less dense medium, its speed decreases (unlike light) … however, like all waves when traveling between two mediums, the frequency remains constant. Based on $v = f\lambda$, if the speed decreases and the frequency is constant then the λ must decrease also.	B
7.	Open–closed pipes only have odd multiples of harmonic so next f is 3x f_1	D
8.	For a given medium, speed is constant. Doubling the frequency halves the wavelength	A
9.	Determine each separate frequency using the speed of sound as 340 and $v = f\lambda$. Then subtract the two frequencies to get the beat frequency.	B
10.	Step the two pulses through each other a little bit at a time and use superposition to see how the amplitudes add. At first the amplitude jumps up rapidly, then the amplitude moves down as the rightmost negative pulse continues to propagate. At the very end of their passing the amplitude would be all the wave down and then once they pass the point will jump back up to equilibrium	C
11.	Wavelengths of each are (dist/cycle) … 4L, 4/3 L, 4/5 L, L, 2/3 L … Frequencies are $f = v/\lambda$. v/4L, 3v/4L, 5v/4L, v/L, 3v/2L … Oy is 2x Cy	B,C
12.	f = cycles / seconds	D
13.	To use $v = f\lambda$, you also need the λ	B
14.	To produce pipe harmonics, the ends are always antinodes. The first (fundamental) harmonic is when there are two antinodes on the end and one node in-between. To move to each next harmonic, add another node in the middle and fill in the necessary antinodes. (ex, 2nd harmonic is ANANA … So the 4th harmonic would be ANANANANA and have four nodes. *Alternative solution … if you know what the harmonics look like you can draw them and manually count the nodes.*	C
15.	Since the medium stays the same the speed remains constant. Based on $v = f\lambda$, for constant speed, f and λ change as inverses.	A
16.	We should look at the harmonic shapes open–open vs open–closed.	D

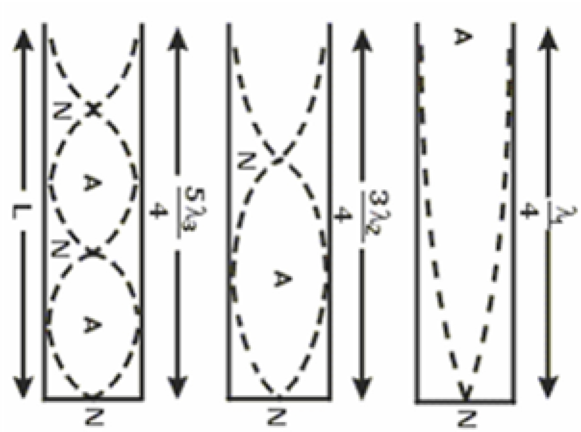
L_1 L_2

Comparing the fundamental harmonic of the open–open pipe to the closed–open pipe. The closed–open pipe should be half as long as the open–open pipe in order to fit the proper number of wavelengths of the same waveform to produce the given harmonic in each.

17. Two antinodes by definition will be ½ λ apart. So 20 cm = ½ λ, and the λ = 40 cm. Then using v = f λ we have 1200 = f (40) D

18. This is similar to question 26, except now the length of the tube remains constant and the wave is changing within the tube to make each successive waveform (this would be like using different tuning forks each time for the same tube). The diagrams would look like this now: C

5 3 1



Each λ is given by λ = dist / cycle
So
$\lambda_1 = 4L$
$\lambda_3 = 4/3\ L$
$\lambda_5 = 4/5\ L$

19. Doppler effect. The waves at right are compressed because the object is moving right. However, the waves are moving faster than the object since they are out in front of where the object is. B

20. The time to make 1 cycle, is also the time it takes the wave to travel 1 λ. A

21. Superpose the two waves on top of each other to get the answer. B

22. Based on the diagram, the λ is clearly 2m. Plug into v = f λ. D

23. The diagram shows the second harmonic in the string. Since harmonics are multiples, the first harmonic would be half of this. B

24. A fact about the Doppler effect. Can also be seen from the Doppler equation (which is not required). B, C

25. Use superposition and overlap the waves to see the resultant. A

26. When hitting a fixed boundary, some of the wave is absorbed, some is reflected inverted. The reflected wave has less amplitude since some of the wave is absorbed, but since the string has not changed its properties the speed of the wave should remain unchanged. C, D

27. Clearly at point C the waves are compressed so are more frequent. C

28. Harmonics are multiples of the fundamental so the fundamental must be f/2. B

29. Based on the Doppler effect, only speed matters. The faster a vehicle is moving, the closer together the sound waves get compressed and the higher the frequency. Take the case of a very fast vehicle traveling at the speed of sound; the compressions are all right on top of each other. So faster speed means closer compressions and higher frequencies. Choice I must be true because X is a higher frequency so must be going faster. Distance to the person affects the volume but not the pitch so choice II is wrong. III seems correct but its not. It doesn't matter whether you are speeding up or slowing down, it only matters who is going faster. For example, suppose truck X was going 5 mph and speeding up while truck Y was going 50 mph and slowing A,D

down, this is an example of choice III but would not meet the requirement that X has a higher frequency because only actual speed matters, not what is happening to that speed.

30. By inspection. A

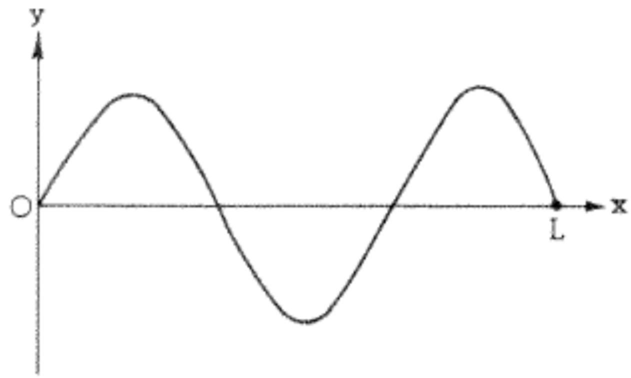
31. By inspection, the λ is 10 cm. f = 1 / T = 5, Then use v = f λ. C

32. A,C

Based on $v = \sqrt{\frac{F_t}{m/l}}$, the tension changes the speed. Then based on $f_n = \frac{nv}{2L}$, this resulting speed change will effect the frequency also. But since the frequency increases in direct proportion to the speed, and v = f λ, the λ should remain unchanged.
Note: equation of wave speed not required

1975B4.

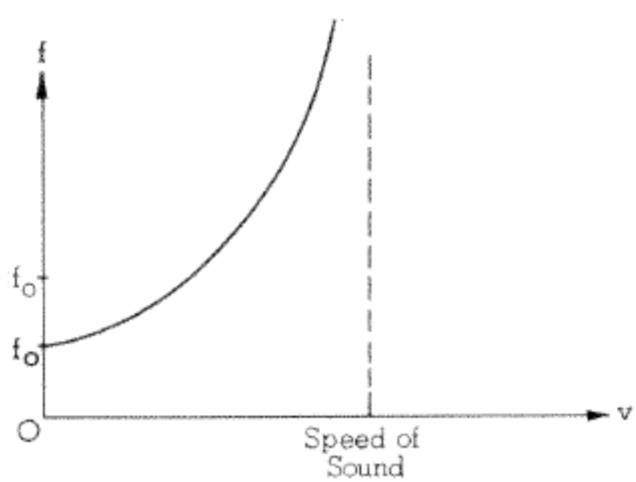
c) simple graph with 1.5x the frequency



d) Graphs are based on the Doppler equation. The graph given in the problem is for a moving observer.

Which is based on $f' = f\frac{(v_{snd} + v_{obs})}{v_{snd}}$. As the observer's velocity increases, the frequency increases linearly with it as is shown in the problem

The new graph is based on a source moving towards you. $f' = f\frac{v_{snd}}{(v_{snd} - v_{source})}$. As can be seed from this equation, as the source increases velocity, the frequency increases but when the source approaches the speed of sound, the frequency approaches ∞ and becomes undefined so has a limit to it unlike in the first graph.



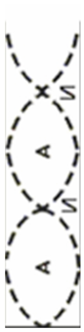
1995B6.

a) The fundamental in a open–open pipe looks like this  and is ½ of a wavelength of the wave. Since this ½ wavelength fits in the length L, the total wavelength would have to be 2L.

b) Simply use $v = f\lambda \rightarrow v = 2Lf_o$

c) Harmonics are multiples of the fundamental, so the next frequency is $2f_o$

d) This is the same tuning fork so it is the same wavelength and waveform but the bottom is now closed so the wave looks like this.



The tube we had initially, fit ½ of a wavelength inside, and since its the same wavelength wave, again ½ of the wavelength of this wave would fit in length L and it would look like this.

This is impossible for a <u>standing wave</u> in an open–closed tube, and its also not the fundamental anyway so we have to change the length to make it look like the fundamental, Shown below. To do this, we make the length half of what it used to be.

$\boxed{h = L/2}$

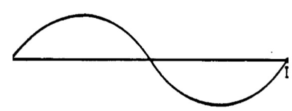
1998B5.

a) λ = dist / cycles = 1.2 m / 4 = 0.60 m

b) $v = f\lambda = (120)(0.60) = 72$ m/s

c) More 'loops' means a smaller wavelength. The frequency of the tuning fork is constant. Based on $v = f\lambda$, less speed would be required to make smaller wavelength. Since speed is based on tension, less M, makes less speed.

d) In one full cycle, a point on a wave covers 4 amplitudes … up, down, down, up. … So the amplitude is 1 cm.



B2004B3.

a) The shortest length makes the fundamental which looks like this  and is ¼ of the wavelength. This length is known to be 0.25m. So $L_1 = ¼ \lambda$ … $\lambda = 4L_1 = 1$m.

Note: This is a real experiment, and in the reality of the experiment it is known that the antinode of the wave actually forms slightly above the top of the air column (you would not know this unless you actually performed this experiment). For this reason, the above answer is technically not correct as the tube length is slightly less than 1/4 of the wavelength. The better way to answer this question is to use the two values they give you for each consecutive harmonic. You are given the length of the first frequency (fundamental), and the length of the second frequency (third harmonic). Based on the known shapes of these harmonics, the difference in lengths between these two harmonics is equal to ½ the wavelength of the wave. Applying this →

$\Delta L = ½ \lambda$ … $0.8–0.25 = ½ \lambda$ $\lambda_{actual} = 1.1$ m.

Unfortunately the AP exam scored this question assuming you knew about the correction; though you received 3 out of 4 points for using the solution initially presented. We teachers, the authors of this solution guide, feel this is a bit much to ask for.

b) Using $v = f \lambda$ with the actual λ … $(340) = f(1.1)$ … $f = 312$ Hz.

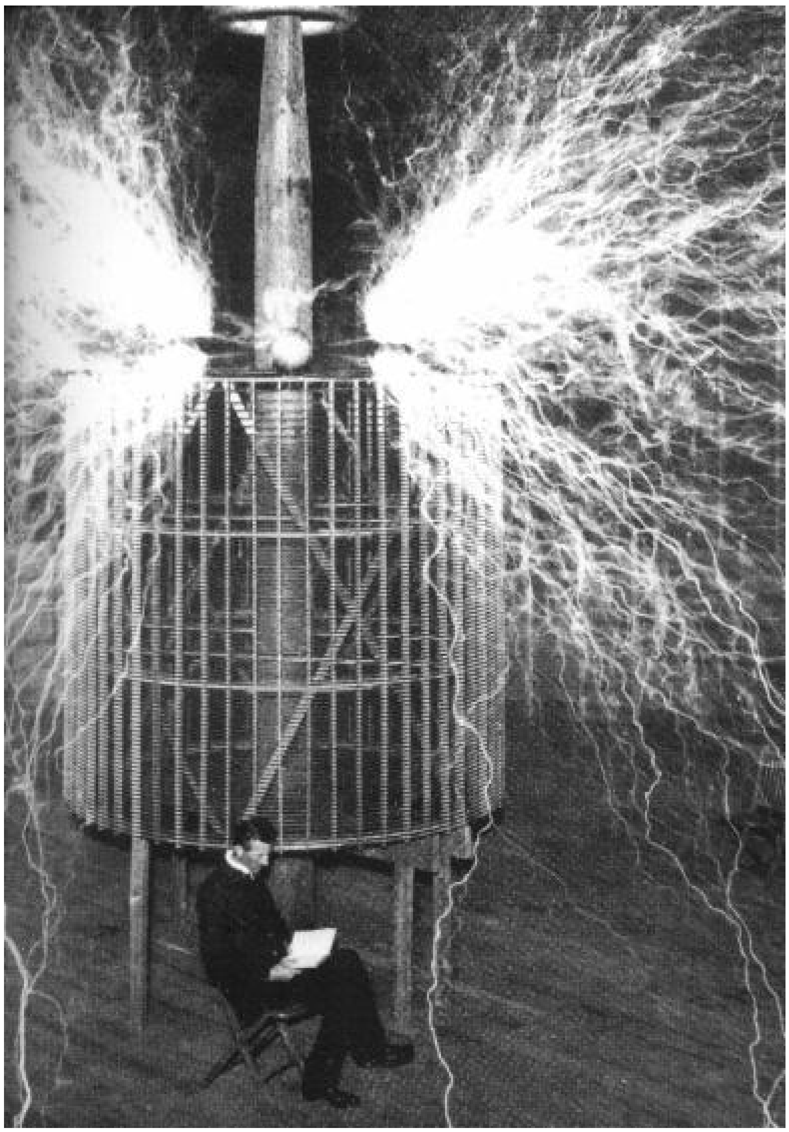
c) $v = f \lambda$ … $(1490) = (312) \lambda_{water}$ … $\lambda_{water} = 4.8$ m

d) Referring to the shapes of these harmonics is useful. The second length L_3 was the 3rd harmonic. The next harmonic (5th) will occur by adding another ½λ to the wave (based on how it looks you can see this). This will give a total length of $L_2 + ½ \lambda = (0.8) + ½ (1.1) = 1.35$ m

e) As temperature increases, the speed of sound in air increases, so the speed used in part (b) was too low. Since $f = v_{air} / \lambda$, that lower speed of sound yielded a frequency that was too low.

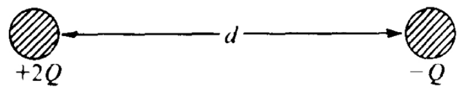
Chapter 10

Electrostatics



AP Physics Multiple Choice Practice – Electrostatics

1. A solid conducting sphere is given a positive charge Q. How is the charge Q distributed in or on the sphere?
   (A) It is concentrated at the center of the sphere.
   (B) It is uniformly distributed throughout the sphere.
   (C) Its density increases radially outward from the center.
   (D) It is uniformly distributed on the surface of the sphere only.



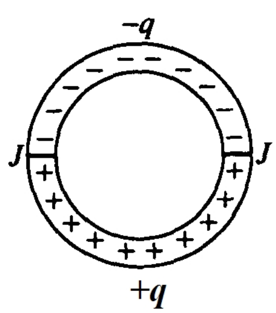
2. Two identical conducting spheres are charged to +2Q and –Q. respectively, and are separated by a distance d (much greater than the radii of the spheres) as shown above. The magnitude of the force of attraction on the left sphere is F_1. After the two spheres are made to touch and then are re-separated by distance d, the magnitude of the force on the left sphere is F_2. Which of the following relationships is correct?
   (A) $2F_1 = F_2$ (B) $F_1 = F_2$ (C) $F_1 = 2F_2$ (D) $F_1 = 8F_2$

3. Two isolated charges, + q and – 2q, are 2 centimeters apart. If F is the magnitude of the force acting on charge –2Q, what are the magnitude and direction of the force acting on charge +q?

	Magnitude	Direction
(A)	2 F	Away from charge –2q
(B)	F	Toward charge – 2q
(C)	F	Away from charge – 2q
(D)	2F	Toward charge – 2q

4. **Multiple correct:** Forces between two objects which are inversely proportional to the square of the distance between the objects include which of the following? Select two answers:
   A.. Gravitational force between two celestial bodies
   B. Electrostatic force between two electrons
   C. Nuclear force between two neutrons
   D. Magnetic force between two magnets

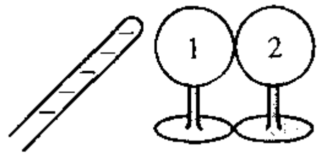
5. Two small spheres have equal charges q and are separated by a distance d. The force exerted on each sphere by the other has magnitude F. If the charge on each sphere is doubled and d is halved, the force on each sphere has magnitude
   (A) F (B) 2F (C) 8F (D) 16F



6. A circular ring made of an insulating material is cut in half. One half is given a charge –q uniformly distributed along its arc. The other half is given a charge + q also uniformly distributed along its arc. The two halves are then rejoined with insulation at the junctions J, as shown above. If there is no change in the charge distributions, what is the direction of the net electrostatic force on an electron located at the center of the circle?
   (A) Toward the top of the page (B) Toward the bottom of the page (C) To the right D) To the left

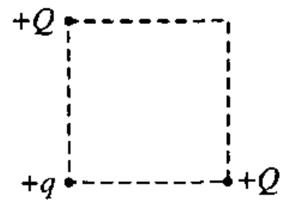
7. Two metal spheres that are initially uncharged are mounted on insulating stands, as shown above. A negatively charged rubber rod is brought close to, but does not make contact with, sphere X. Sphere Y is then brought close to X on the side opposite to the rubber rod. Y is allowed to touch X and then is removed some distance away. The rubber rod is then moved far away from X and Y. What are the final charges on the spheres?

	Sphere X	Sphere Y
A)	Negative	Negative
B)	Negative	Positive
C)	Positive	Negative
D)	Positive	Positive

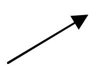
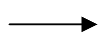
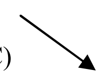
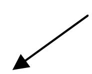


8. Two initially uncharged conductors, 1 and 2, are mounted on insulating stands and are in contact, as shown above. A negatively charged rod is brought near but does not touch them. With the rod held in place, conductor 2 is moved to the right by pushing its stand, so that the conductors are separated. Which of the following is now true of conductor 2?
(A) It is uncharged. (B) It is positively charged. (C) It is negatively charged.
(D) It is charged, but its sign cannot be predicted.

Questions 9-10



9. As shown above, two particles, each of charge +Q, are fixed at opposite corners of a square that lies in the plane of the page. A positive test charge +q is placed at a third corner. What is the direction of the force on the test charge due to the two other charges?

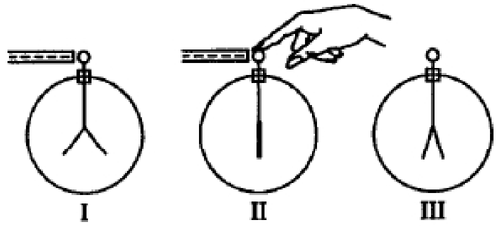
(A)  (B)  (C)  (D) 

10. If F is the magnitude of the force on the test charge due to only one of the other charges, what is the magnitude of the net force acting on the test charge due to both of these charges?

(A) $\frac{F}{\sqrt{2}}$ (B) F (C) $\sqrt{2}F$ (D) 2

11. Suppose that an electron (charge –e) could orbit a proton (charge +e) in a circular orbit of constant radius R. Assuming that the proton is stationary and only electrostatic forces act on the particles, which of the following represents the kinetic energy of the two–particle system?

(A) $\frac{1}{8\pi\varepsilon_0}\frac{e^2}{R}$ (B) $-\frac{1}{8\pi\varepsilon_0}\frac{e^2}{R}$ (C) $\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R^2}$ (D) $-\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R^2}$

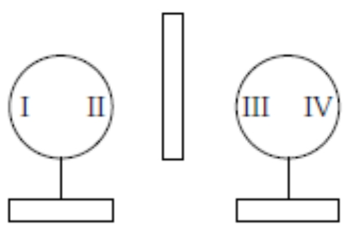


12. When a negatively charged rod is brought near, but does not touch, the initially uncharged electroscope shown above, the leaves spring apart (I). When the electroscope is then touched with a finger, the leaves collapse (II). When next the finger and finally the rod are removed, the leaves spring apart a second time (III). The charge on the leaves is
(A) positive in both I and III
(B) negative in both I and III
(C) positive in I, negative in III
(D) negative in I, positive in III

13. **Multiple Correct.** A positively charged conductor attracts a second object. Which of the following statements *could* be true? Select two answers
    A. The second object is a conductor with positive net charge.
    B. The second object is a conductor with zero net charge.
    C. The second object is an insulator with zero net charge.
    D. The second object is an insulator with positive net charge.

14. Two positive point charges repel each other with force 0.36 N when their separation is 1.5 m. What force do they exert on each other when their separation is 1.0 m?
(A) 0.81 N (B) 0.36 N (C) 0.24 N (D) 0.16 N

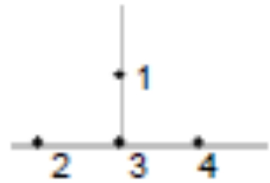
15. A point charge +q is placed midway between two point charges +3q and –q separated by a distance 2d. If Coulomb's constant is k, the magnitude of the force on the charge +q is:
(A) $2\frac{kq^2}{d^2}$ (B) $4\frac{kq^2}{d^2}$ (C) $6\frac{kq^2}{d^2}$ (D) $9\frac{kq^2}{d^2}$



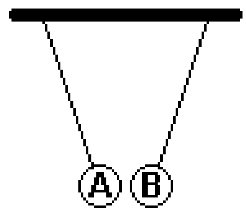
16. A charged rod is placed between two insulated conducting spheres as shown. The spheres have no net charge. Region II has the same polarity as Region
(A) I only (B) III only (C) IV only (D) I & IV only

17. When two charged point–like objects are separated by a distance *R*, the force between them is *F*. If the distance between them is quadrupled, the force between them is
(A) 16 *F* (B) 4 *F* (C) *F*/4 (D) *F*/16

18. An electroscope is given a positive charge, causing its foil leaves to separate. When an object is brought near the top plate of the electroscope, the foils separate even further. We could conclude
(A) that the object is positively charged.
(B) that the object is electrically neutral.
(C) that the object is negatively charged.
(D) only that the object is charged.



19. Four positive point charges are arranged as shown in the accompanying diagram. The force between charges 1 and 3 is 6.0 N; the force between charges 2 and 3 is 5.0 N; and the force between charges 3 and 4 is 3.0 N. The magnitude of the total force on charge 3 is most nearly
(A) 6.3 N (B) 8.0 N (C) 10 N (D) 11 N (E) 14 N



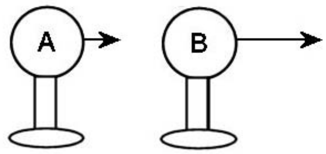
20. Two small hollow metal spheres hung on insulating threads attract one another as shown. It is known that a positively charged rod will attract ball A.
Which of the statements can be correctly concluded about the charge on the balls?
A. Ball A has a positive charge
B. Ball B has a negative charge
C. Ball A and Ball B have opposite charges
D. Ball A is neutral

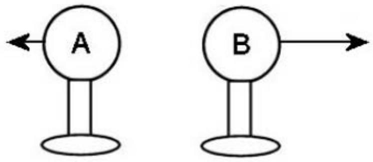
21. Two identical electrical point charges Q, separated by a distance d produce an electrical force of F on one another. If the distance is decreased to a distance of $0.40d$, what is the strength of the resulting force?
(A) $6.3F$ (B) $2.5F$ (C) $0.40F$ (D) $0.16F$

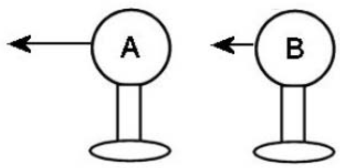
22. A positively charged object is brought near but not in contact with the top of an uncharged gold leaf electroscope. The experimenter then briefly touches the electroscope with a finger. The finger is removed, followed by the removal of the positively charged object. What happens to the leaves of the electroscope when a negative charge is now brought near but not in contact with the top of the electroscope?
(A) they remain uncharged
(B) they move farther apart
(C) they move closer together
(D) they remain negatively charged but unmoved

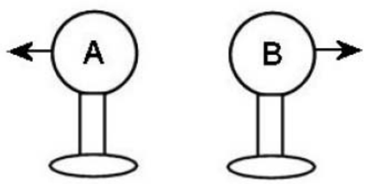
23. A positive point charge exerts a force of magnitude F on a negative point charge placed a distance x away. If the distance between the two point charges is halved, what is the magnitude of the new force that the positive point charge exerts on the negative point charge?
(A) $4F$ (B) $2F$ (C) $F/2$ (D) F/4

24. Two uniformly charged non–conducting spheres on insulating bases are placed on an air table. Sphere A has a charge $+3Q$ coulombs and sphere B has a charge $+Q$ coulombs. Which of the following correctly illustrates the magnitude and direction of the electrostatic force between the spheres when they are released?

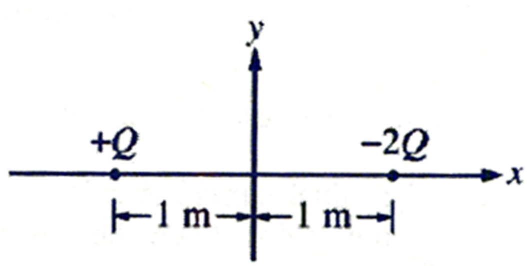
(A) 

(B) 

(C) 

(D) 

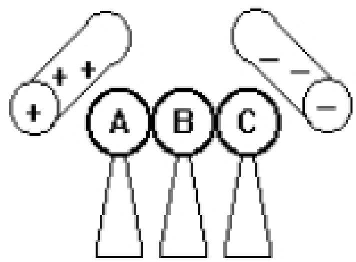
25. A person rubs a neutral comb through their hair and the comb becomes negatively charged. Which of the following is the best explanation for this phenomenon?
(A) The hair gains protons from the comb.
(B) The hair gains protons from the comb while giving electrons to the comb.
(C) The hair loses electrons to the comb.
(D) The comb loses protons to the person's hand while also gaining electrons from the hair.



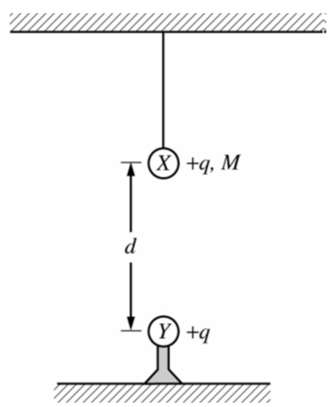
26. A charge of $+Q$ is located on the x–axis at $x = -1$ meter and a charge of $-2Q$ is held at $x = +1$ meter, as shown in the diagram above. At what position on the x–axis will a test charge of $+q$ experience a zero net electrostatic force?
(A) $-(3+\sqrt{8})$ m (B) $-1/3$ m (C) $1/3$ m (D) $(3+\sqrt{8})$ m

27. Two point objects each carrying charge $10Q$ are separated by a distance d. The force between them is F. If half the charge on one object is transferred to the other object while at the same time the distance between them is doubled, what is the new force between the two objects?
(A) 0.19 F (B) 0.25 F (C) 4.0 F (D) no change in F

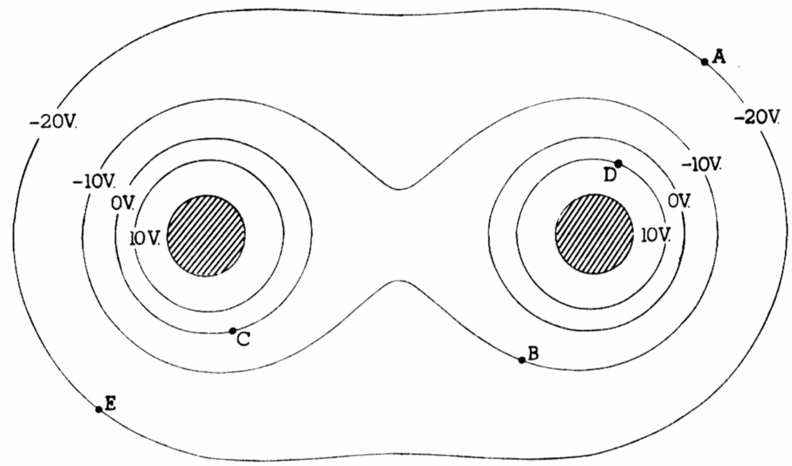
28. Two identical spheres carry identical electric charges. If the spheres are set a distance d apart they repel one another with a force F. A third sphere, identical to the other two but initially uncharged is then touched to one sphere and then to the other before being removed. What would be the resulting force between the original two spheres?
(A) ¾ F (B) 5/8 F (C) ½ F (D) 3/8 F



29. Three metal spheres A, B, and C are mounted on insulating stands. The spheres are touching one another, as shown in the diagram below. A strong positively charged object is brought near sphere A and a strong negative charge is brought near sphere C. While the charged objects remain near spheres A and C, sphere B is removed by means of its insulating stand. After the charged objects are removed, sphere B is first touched to sphere A and then to sphere C. The resulting charge on B would be of what relative amount and sign?
(A) the same sign but 1/2 the magnitude as originally on sphere A
(B) the opposite sign but 1/2 the magnitude as originally on sphere A
(C) the opposite sign but 1/4 the magnitude as originally on sphere A
(D) the same sign but 1/2 the magnitude as originally on sphere C

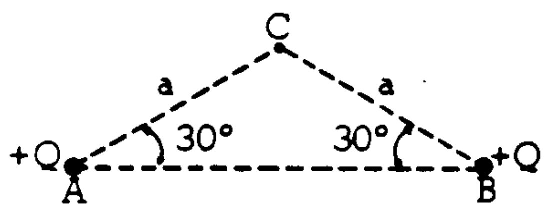


30. Sphere X of mass M and charge $+q$ hangs from a string as shown above. Sphere Y has an equal charge $+q$ and is fixed in place a distance d directly below sphere X. If sphere X is in equilibrium, the tension in the string is most nearly
(A) Mg (B) $Mg - kq/d$ (C) $Mg + kq^2/d^2$ (D) $Mg - kq^2/d^2$

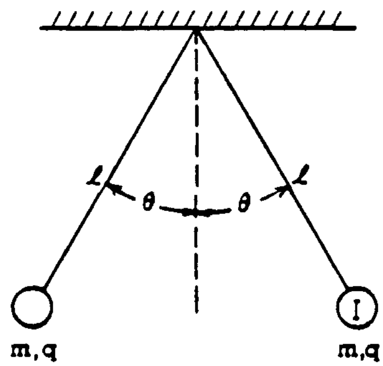


1974B5. The diagram above shows some of the equipotentials in a plane perpendicular to two parallel charged metal cylinders. The potential of each line is labeled.

a. The left cylinder is charged positively. What is the sign of the charge on the other cylinder?
b. On the diagram above, sketch lines to describe the electric field produced by the charged cylinders.
c. Determine the potential difference, $V_A - V_B$, between points A and B.
d. How much work is done by the field if a charge of 0.50 coulomb is moved along a path from point A to point E and then to point D?



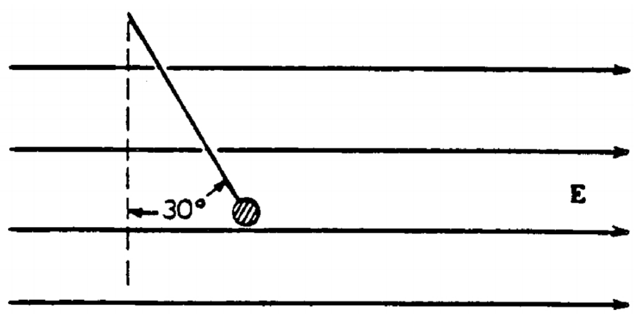
1975B2. Two identical electric charges +Q are located at two corners A and B of an isosceles triangle as shown above.
a. How much work does the electric field do on a small test charge +q as the charge moves from point C to infinity,
b. In terms of the given quantities, determine where a third charge +2Q should be placed so that the electric field at point C is zero. Indicate the location of this charge on the diagram above.



1979B7. Two small spheres, each of mass m and positive charge q, hang from light threads of lengths l. Each thread makes an angle θ with the vertical as shown above.

a. On the diagram draw and label all forces on sphere I.

b. Develop an expression for the charge q in terms of m, l, θ, g, and the Coulomb's law constant.

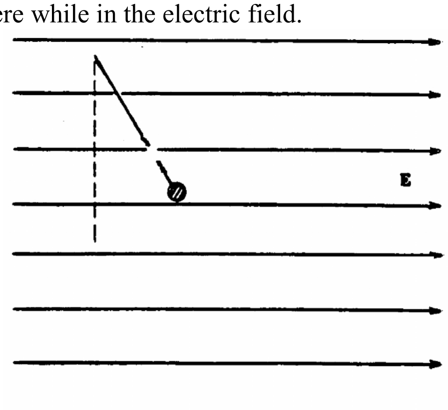


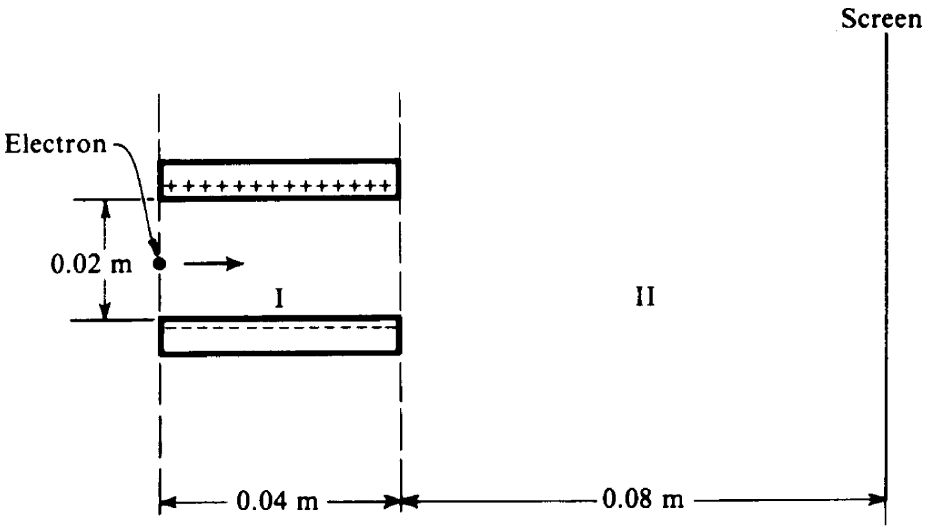
1981B3. A small conducting sphere of mass 5×10^{-3} kilogram, attached to a string of length 0.2 meter, is at rest in a uniform electric field E, directed horizontally to the right as shown above. There is a charge of 5×10^{-6} coulomb on the sphere. The string makes an angle of 30° with the vertical. Assume g = 10 meters per second squared.

a. In the space below, draw and label all the forces acting on the sphere.

b. Calculate the tension in the string and the magnitude of the electric field.

c. The string now breaks. Describe the subsequent motion of the sphere and sketch on the following diagram the path of the sphere while in the electric field.





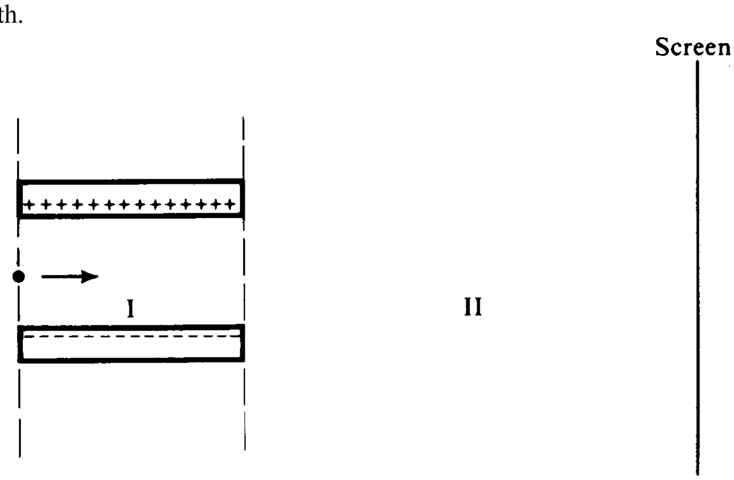
1985B3. An electron initially moves in a horizontal direction and has a kinetic energy of 2.0×10^3 electron–volts when it is in the position shown above. It passes through a uniform electric field between two oppositely charged horizontal plates (region I) and a field–free region (region II) before eventually striking a screen at a distance of 0.08 meter from the edge of the plates. The plates are 0.04 meter long and are separated from each other by a distance of 0.02 meter. The potential difference across the plates is 250 volts. Gravity is negligible.

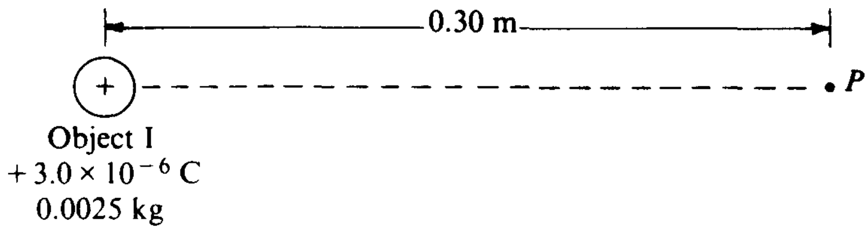
a. Calculate the initial speed of the electron as it enters region I.

b. Calculate the magnitude of the electric field E between the plates, and indicate its direction on the diagram above.

c. Calculate the magnitude of the electric force F acting on the electron while it is in region I.

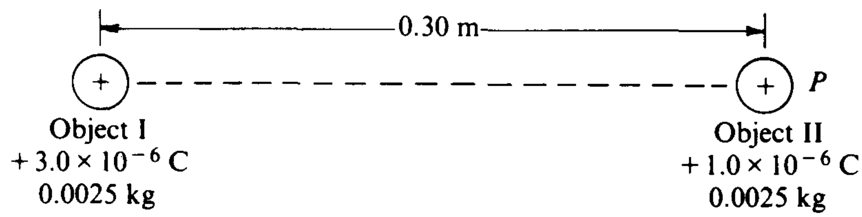
d. On the diagram below, sketch the path of the electron in regions I and II. For each region describe the shape of the path.





1987B2. Object I, shown above, has a charge of + 3 x 10^{-6} coulomb and a mass of 0.0025 kilogram.

a. What is the electric potential at point P, 0.30 meter from object I?

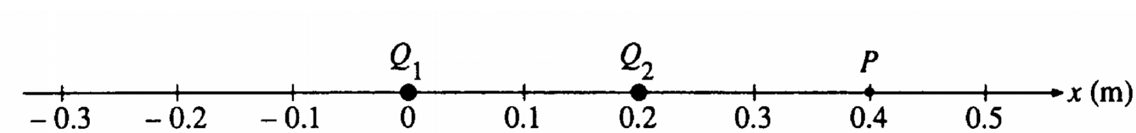


Object II, of the same mass as object I, but having a charge of + 1 x 10^{-6} coulomb, is brought from infinity to point P, as shown above.

b. How much work must be done to bring the object II from infinity to point P?
c. What is the magnitude of the electric force between the two objects when they are 0.30 meter apart?
d. What are the magnitude and direction of the electric field at the point midway between the two objects?

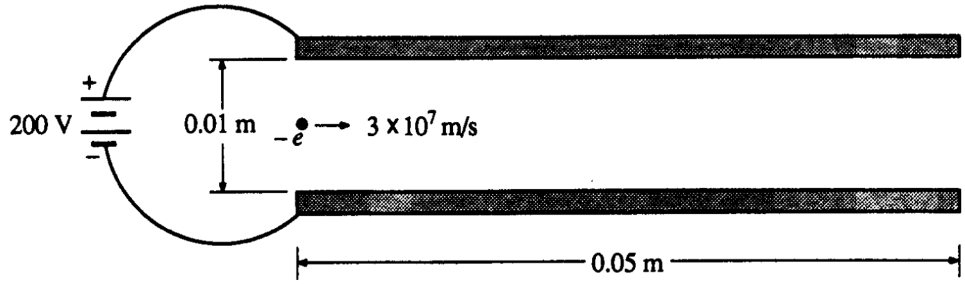
The two objects are then released simultaneously and move apart due to the electric force between them. No other forces act on the objects.

e. What is the speed of object I when the objects are very far apart?



1989B2. Two point charges, Q_1 and Q_2, are located a distance 0.20 meter apart, as shown above. Charge Q_1 = +8.0μC. The net electric field is zero at point P, located 0.40 meter from Q_1 and 0.20 meter from Q_2.

a. Determine the magnitude and sign of charge Q_2.
b. Determine the magnitude and direction of the net force on charge Q_1
c. Calculate the electrostatic potential energy of the system.
d. Determine the coordinate of the point R on the x–axis between the two charges at which the electric potential is zero.
e. How much work is needed to bring an electron from infinity to point R. which was determined in the previous part?



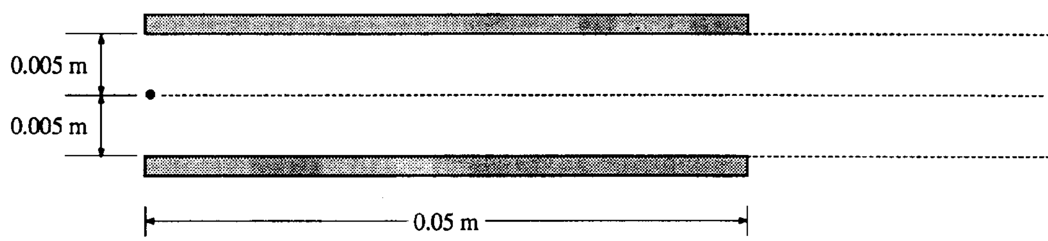
1990B2 (modified) A pair of square parallel conducting plates, having sides of length 0.05 meter, are 0.01 meter apart and are connected to a 200–volt power supply, as shown above. An electron is moving horizontally with a speed of 3×10^7 meters per second when it enters the region between the plates. Neglect gravitation and the distortion of the electric field around the edges of the plates.

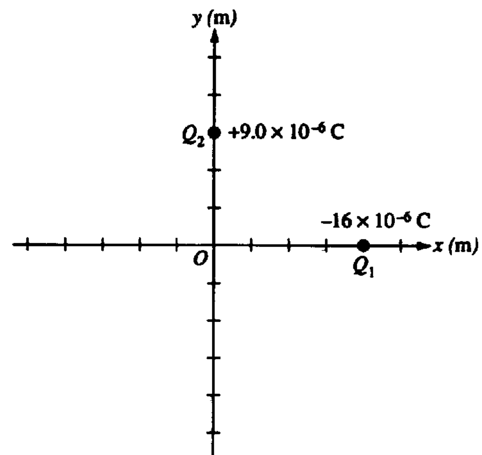
a. Determine the magnitude of the electric field in the region between the plates and indicate its direction on the figure above.

b. Determine the magnitude and direction of the acceleration of the electron in the region between the plates.

c. Determine the magnitude of the vertical displacement of the electron for the time interval during which it moves through the region between the plates.

d. On the diagram below, sketch the path of the electron as it moves through and after it emerges from the region between the plates. The dashed lines in the diagram have been added for reference only.



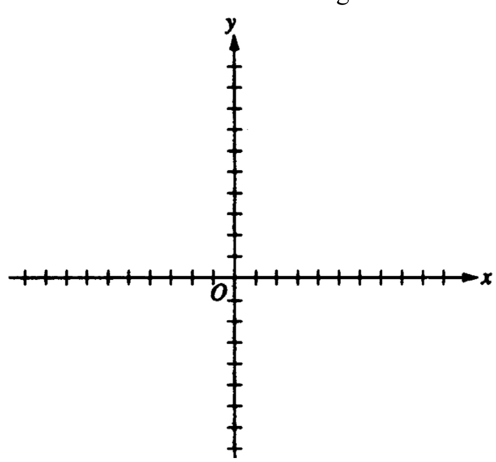


1993B2. A charge $Q_1 = -1.6 \times 10^{-6}$ coulomb is fixed on the x–axis at +4.0 meters, and a charge $Q_2 = +9 \times 10^{-6}$ coulomb is fixed on the y–axis at +3.0 meters, as shown on the diagram above.

a. i. Calculate the magnitude of the electric field E_1 at the origin O due to charge Q_1

ii. Calculate the magnitude of the electric field E_2 at the origin O due to charge Q_2.

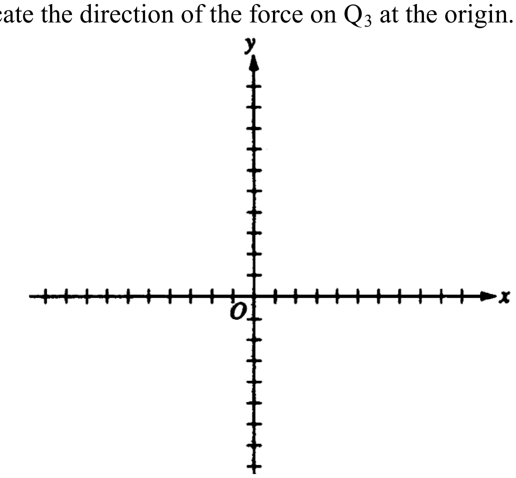
iii. On the axes below, draw and label vectors to show the electric fields E_1 and E_2 due to each charge, and also indicate the resultant electric field E at the origin.



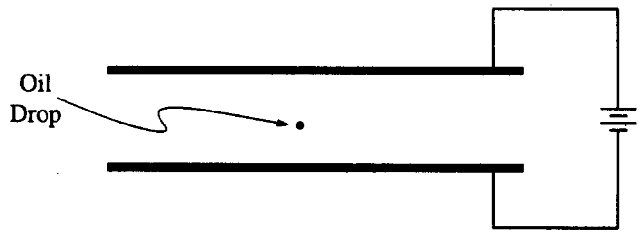
b. Calculate the electric potential V at the origin.

A charge $Q_3 = -4 \times 10^{-6}$ coulomb is brought from a very distant point by an external force and placed at the origin.

c. On the axes below, indicate the direction of the force on Q_3 at the origin.

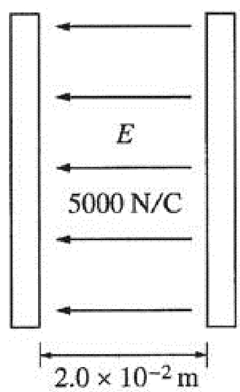


d. Calculate the work that had to be done by the external force to bring Q_3 to the origin from the distant point.



1996B6 Robert Millikan received a Nobel Prize for determining the charge on the electron. To do this, he set up a potential difference between two horizontal parallel metal plates. He then sprayed drops of oil between the plates and adjusted the potential difference until drops of a certain size remained suspended at rest between the plates, as shown above. Suppose that when the potential difference between the plates is adjusted until the electric field is 10,000 N/C downward, a certain drop with a mass of 3.27×10^{-16} kg remains suspended.

a. What is the magnitude of the charge on this drop?
b. The electric field is downward, but the electric force on the drop is upward. Explain why.
c. If the distance between the plates is 0.01 m, what is the potential difference between the plates?
d. The oil in the drop slowly evaporates while the drop is being observed, but the charge on the drop remains the same. Indicate whether the drop remains at rest, moves upward, or moves downward. Explain briefly.



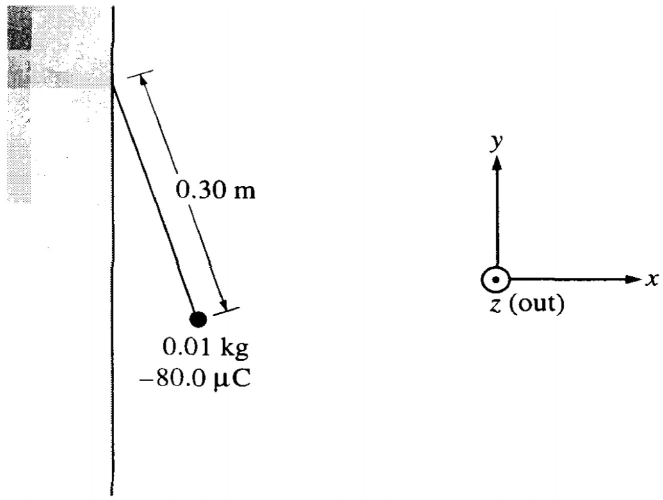
Note: Figure not drawn to scale.

2002B5B. Two parallel conducting plates, each of area 0.30 m^2, are separated by a distance of 2.0×10^{-2} m of air. One plate has charge +Q; the other has charge –Q. An electric field of 5000 N/C is directed to the left in the space between the plates, as shown in the diagram above.

a. Indicate on the diagram which plate is positive (+) and which is negative (–).
b. Determine the potential difference between the plates.
c. Determine the capacitance of this arrangement of plates.

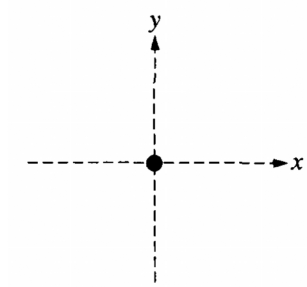
An electron is initially located at a point midway between the plates.

d. Determine the magnitude of the electrostatic force on the electron at this location and state its direction.
e. If the electron is released from rest at this location midway between the plates, determine its speed just before striking one of the plates. Assume that gravitational effects are negligible.



1998B2. A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of –80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

a. On the diagram below, draw and label the forces acting on the ball.



b. Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

c. Determine the perpendicular distance from the wall to the center of the ball.

d. The string is now cut.

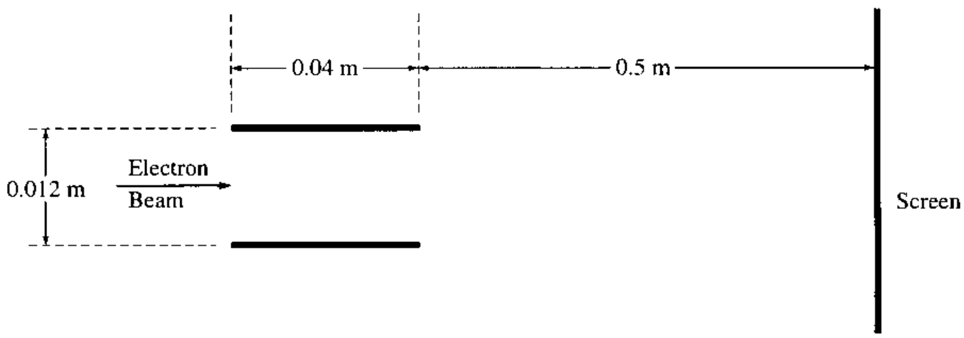
   i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.

   ii. Describe the resulting path of the ball.

1999B2. In a television set, electrons are first accelerated from rest through a potential difference in an electron gun. They then pass through deflecting plates before striking the screen.

a. Determine the potential difference through which the electrons must be accelerated in the electron gun in order to have a speed of 6.0×10^7 m/s when they enter the deflecting plates.

The pair of horizontal plates shown below is used to deflect electrons up or down in the television set by placing a potential difference across them. The plates have length 0.04 m and separation 0.012 m, and the right edge of the plates is 0.50 m from the screen. A potential difference of 200 V is applied across the plates, and the electrons are deflected toward the top of the screen. Assume that the electrons enter horizontally midway between the plates with a speed of 6.0×10^7 m/s and that fringing effects at the edges of the plates and gravity are negligible.



Note: Figure not drawn to scale.

b. Which plate in the pair must be at the higher potential for the electrons to be deflected upward? Check the appropriate box below.

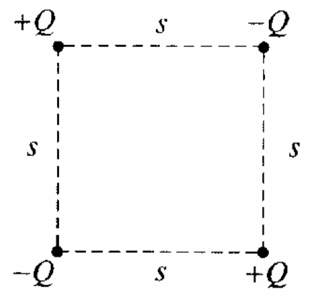
☐ Upper plate ☐ Lower plate

Justify your answer.

c. Considering only an electron's motion as it moves through the space between the plates, compute the following.
i. The time required for the electron to move through the plates
ii. The vertical displacement of the electron while it is between the plates

d. Show why it is a reasonable assumption to neglect gravity in part c.

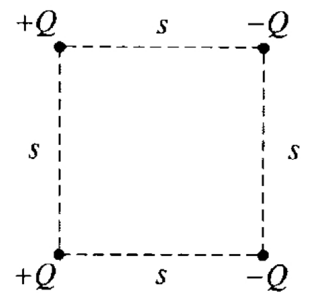
e. Still neglecting gravity, describe the path of the electrons from the time they leave the plates until they strike the screen. State a reason for your answer.



Arrangement 1

2001B3. Four charged particles are held fixed at the corners of a square of side s. All the charges have the same magnitude Q, but two are positive and two are negative. In Arrangement 1, shown above, charges of the same sign are at opposite corners. Express your answers to parts a. and b. in terms of the given quantities and fundamental constants.

a. For Arrangement 1, determine the following.
   i. The electrostatic potential at the center of the square
   ii. The magnitude of the electric field at the center of the square



Arrangement 2

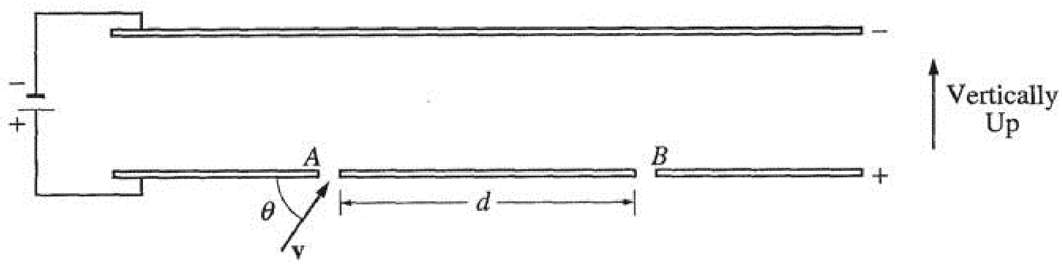
The bottom two charged particles are now switched to form Arrangement 2, shown above, in which the positively charged particles are on the left and the negatively charged particles are on the right.

b. For Arrangement 2, determine the following.
   i. The electrostatic potential at the center of the square
   ii. The magnitude of the electric field at the center of the square

c. In which of the two arrangements would more work be required to remove the particle at the upper right corner from its present position to a distance a long way away from the arrangement?

_________ Arrangement 1 ___________ Arrangement 2

Justify your answer



2003Bb4. An electric field E exists in the region between the two electrically charged parallel plates shown above. A beam of electrons of mass m, charge q, and velocity v enters the region through a small hole at position A. The electrons exit the region between the plates through a small hole at position B. Express your answers to the following questions in terms of the quantities m, q, E, θ, and v. Ignore the effects of gravity.

a. i. On the diagram of the parallel plates above, draw and label a vector to show the direction of the electric field E between the plates.
ii. On the following diagram, show the direction of the force(s) acting on an electron after it enters the region between the plates.

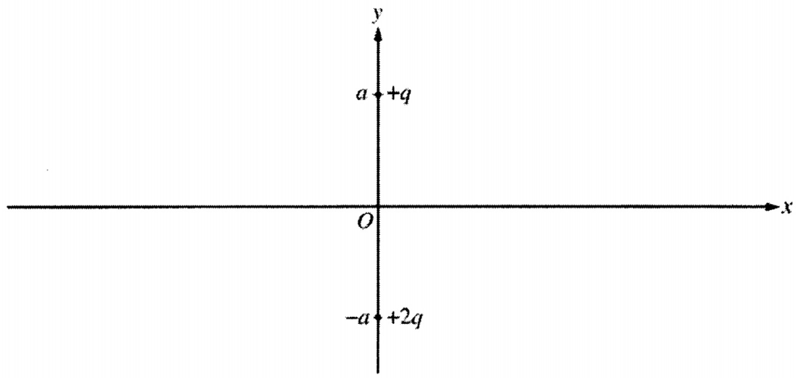
iii. On the diagram of the parallel plates above, show the trajectory of an electron that will exit through the small hole at position B.

b. Determine the magnitude of the acceleration of an electron after it has entered the region between the parallel plates.

c. Determine the total time that it takes the electrons to go from position A to position B.

d. Determine the distance d between positions A and B.

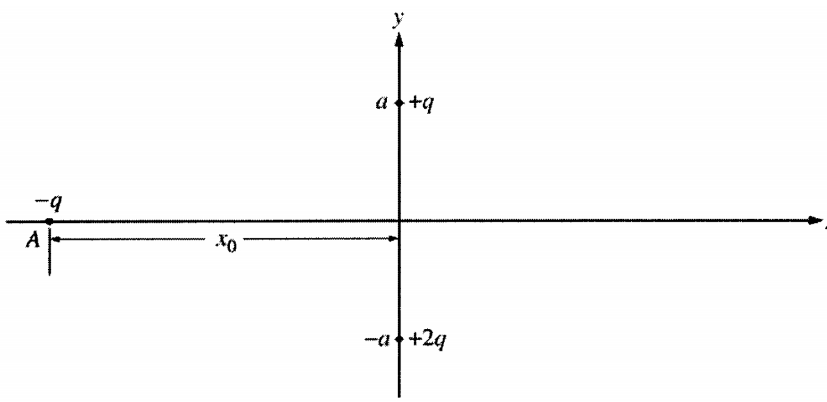
e. Now assume that the effects of gravity cannot be ignored in this problem. How would the distance where the electron exits the region between the plates change for an electron entering the region at A? Explain your reasoning.



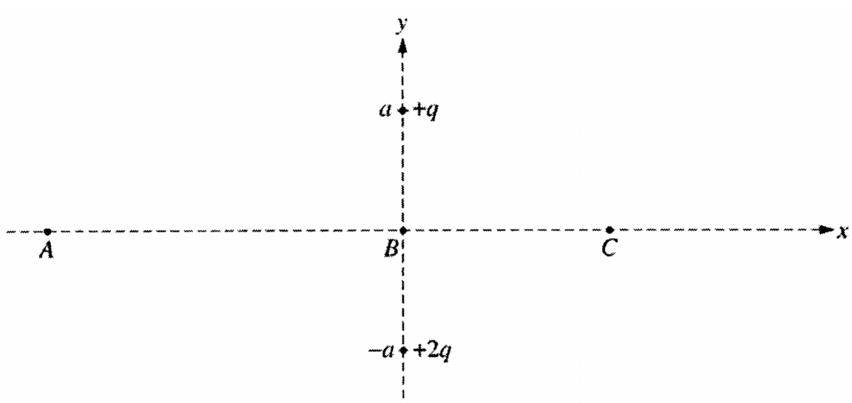
2005B3 Two point charges are fixed on the y–axis at the locations shown in the figure above. A charge of +q is located at y = +a and a charge of +2q is located at y = –a. Express your answers to parts a. and b. in terms of q, a, and fundamental constants.

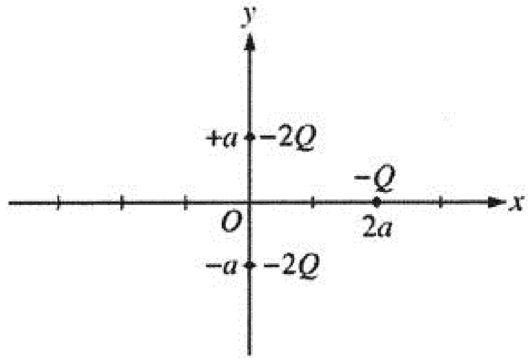
a. Determine the magnitude and direction of the electric field at the origin.
b. Determine the electric potential at the origin.

A third charge of –q is first placed at an arbitrary point A ($x = -x_o$) on the x–axis as shown in the figure below.



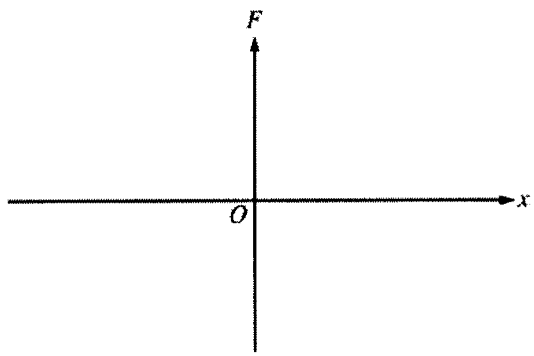
c. Write expressions in terms of q, a, x_0, and fundamental constants for the magnitudes of the forces on the –q charge at point A caused by each of the following.
   i. The +q charge
   ii. The +2q charge
d. The –q charge can also be placed at other points on the x–axis. At each of the labeled points (A, B, and C) in the following diagram, draw a vector to represent the direction of the net force on the –q charge due to the other two charges when it is at those points.

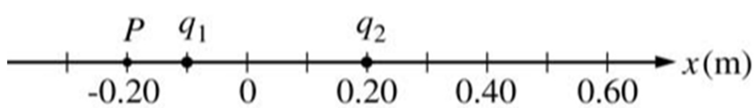




2005Bb3 The figure above shows two point charges, each of charge –2Q, fixed on the y–axis at y = +a and at y = –a. A third point charge of charge –Q is placed on the x–axis at x = 2a. Express all algebraic answers in terms of Q, a, and fundamental constants.

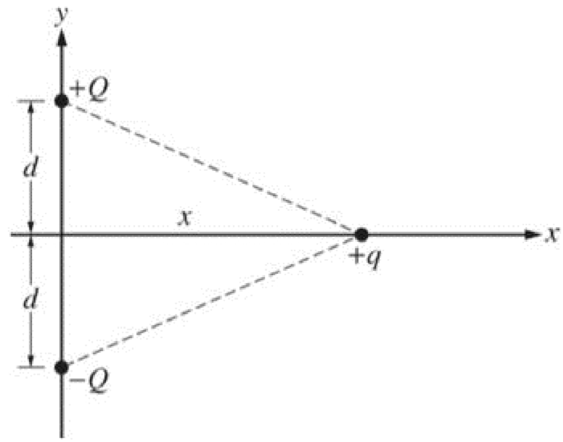
a. Derive an expression for the magnitude of the net force on the charge –Q due to the other two charges, and state its direction.
b. Derive an expression for the magnitude of the net electric field at the origin due to all three charges, and state its direction.
c. Derive an expression for the electrical potential at the origin due to all three charges.
d. On the axes below, sketch a graph of the force F on the –Q charge caused by the other two charges as it is moved along the x–axis from a large positive position to a large negative position. Let the force be positive when it acts to the right and negative when it acts to the left.





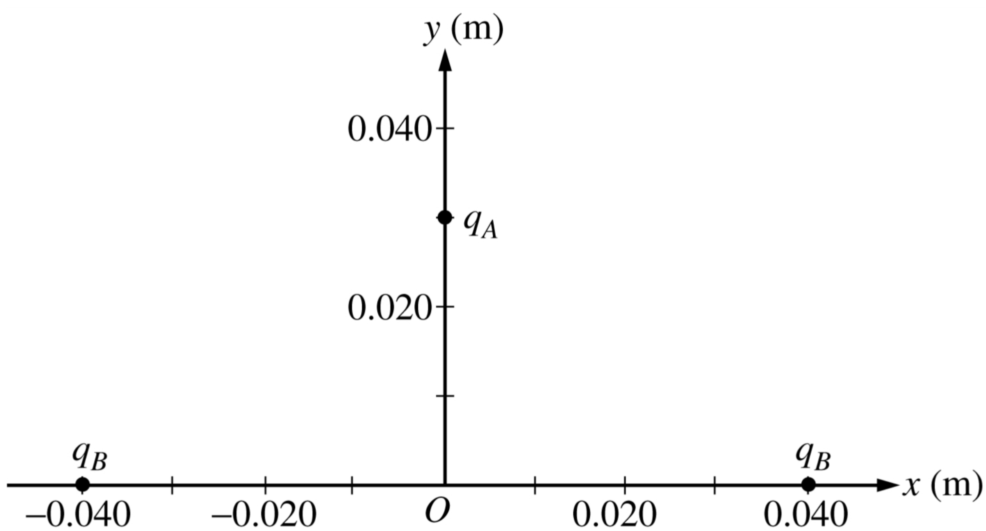
2006B3. Two point charges, q_1 and q_2, are placed 0.30 m apart on the x–axis, as shown in the figure above. Charge q_1 has a value of -3.0×10^{-9} C. The net electric field at point P is zero.

a. What is the sign of charge q_2?
____ Positive ____ Negative
Justify your answer.
b. Calculate the magnitude of charge q_2.
c. Calculate the magnitude of the electric force on q_2 and indicate its direction.
d. Determine the x–coordinate of the point on the line between the two charges at which the electric potential is zero.
e. How much work must be done by an external force to bring an electron from infinity to the point at which the electric potential is zero? Explain your reasoning.



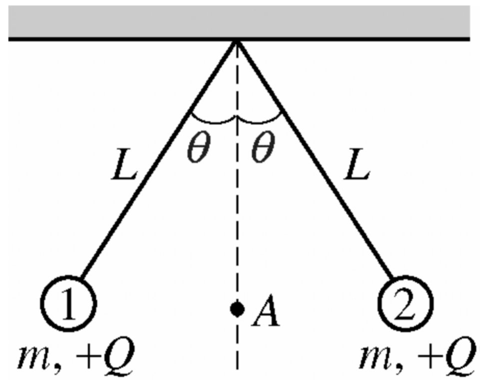
2006Bb3. Three electric charges are arranged on an x–y coordinate system, as shown above. Express all algebraic answers to the following parts in terms of Q, q, x, d, and fundamental constants.

a. On the diagram, draw vectors representing the forces F_1 and F_2 exerted on the +q charge by the +Q and –Q charges, respectively.
b. Determine the magnitude and direction of the total electric force on the +q charge.
c. Determine the electric field (magnitude and direction) at the position of the +q charge due to the other two charges.
d. Calculate the electric potential at the position of the +q charge due to the other two charges.
e. Charge +q is now moved along the positive x–axis to a very large distance from the other two charges. The magnitude of the force on the +q charge at this large distance now varies as $1/x^3$. Explain why this happens.



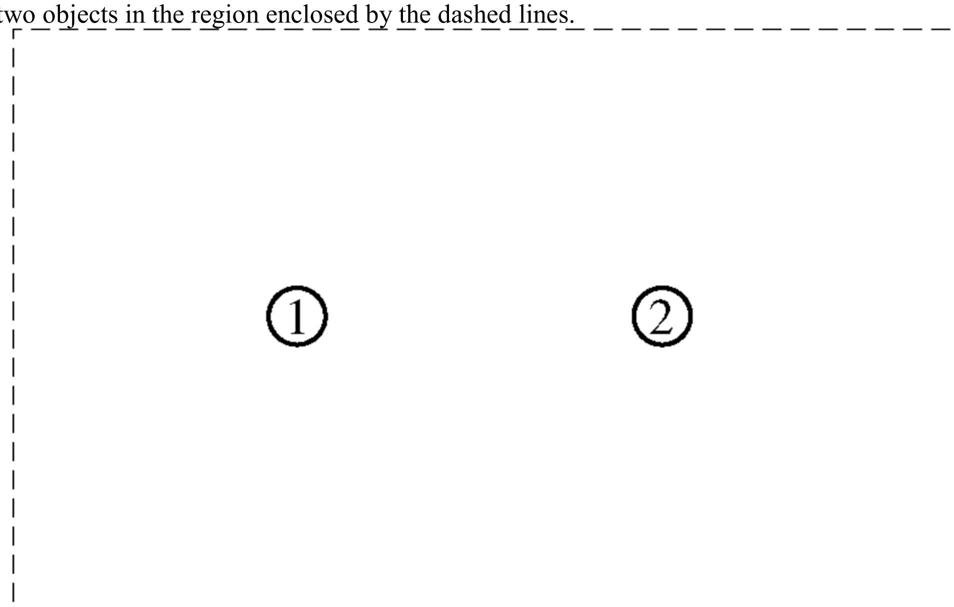
2009B2B.(modified) Three particles are arranged on coordinate axes as shown above. Particle A has charge q_A = –0.20 nC , and is initially on the y–axis at y = 0.030 m. The other two particles each have charge q_B = +0.30 nC and are held fixed on the x–axis at x = –0.040 m and x = +0.040 m, respectively.

a. Calculate the magnitude of the net electric force on particle A when it is at y = 0.030 m, and state its direction.
b. Particle A is then released from rest. Qualitatively describe its motion over a long time.



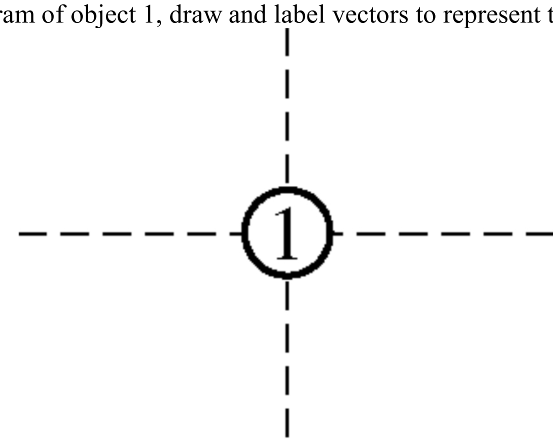
2009B2. Two small objects, labeled 1 and 2 in the diagram above, are suspended in equilibrium from strings of length L. Each object has mass m and charge +Q. Assume that the strings have negligible mass and are insulating and electrically neutral. Express all algebraic answers in terms of m, L, Q, q, and fundamental constants.

a. On the following diagram, sketch lines to illustrate a 2–dimensional view of the net electric field due to the two objects in the region enclosed by the dashed lines.

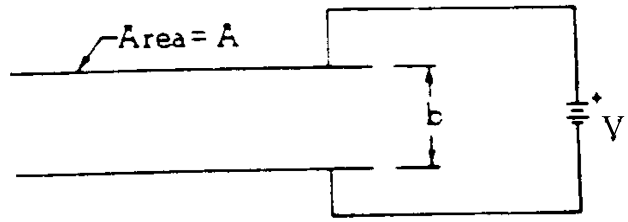


b. Derive an expression for the electric potential at point A, shown in the diagram at the top of the page, which is midway between the charged objects.

c. On the following diagram of object 1, draw and label vectors to represent the forces on the object.



d. Using the conditions of equilibrium, write—but do not solve—two equations that could, together, be solved for q and the tension T in the left–hand string.

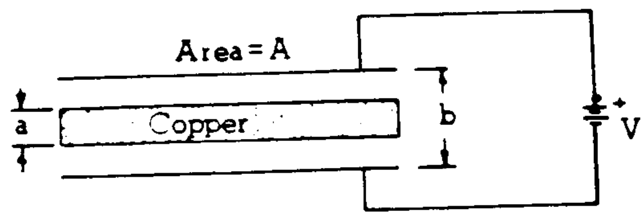


*1974E2. A parallel–plate capacitor with spacing b and area A is connected to a battery of voltage V as shown above. Initially the space between the plates is empty. Make the following determinations in terms of the given symbols.

a. Determine the electric field between the plates.

b. Determine the charge stored on each capacitor plate.

A copper slab of thickness a is now inserted midway between the plates as shown below.



c. Determine the electric field in the spaces above and below the slab.

d. Determine the ratio of capacitances $\frac{C_{with\ copper}}{C_{original}}$ when the slab is inserted

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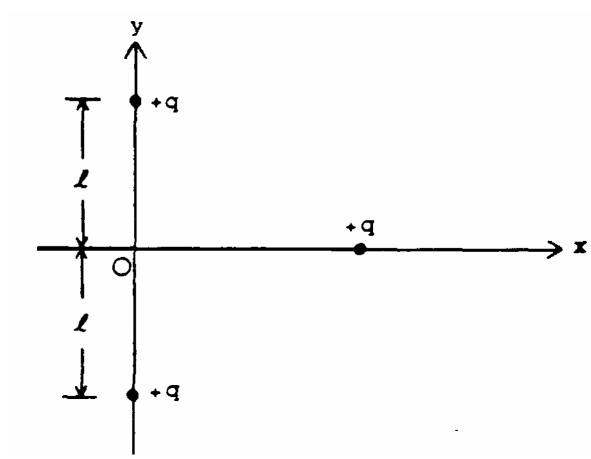
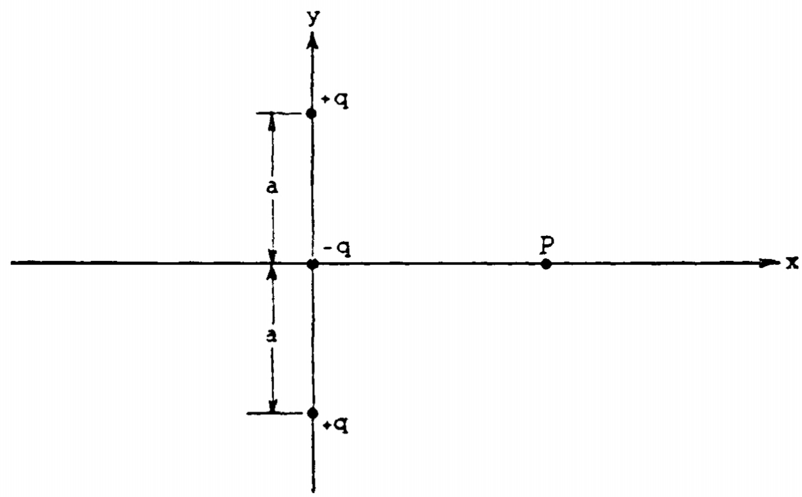


1975E1. Two stationary point charges +q are located on the y–axis as shown above. A third charge +q is brought in from infinity along the x–axis.

a. Express the potential energy of the movable charge as a function of its position on the x–axis.

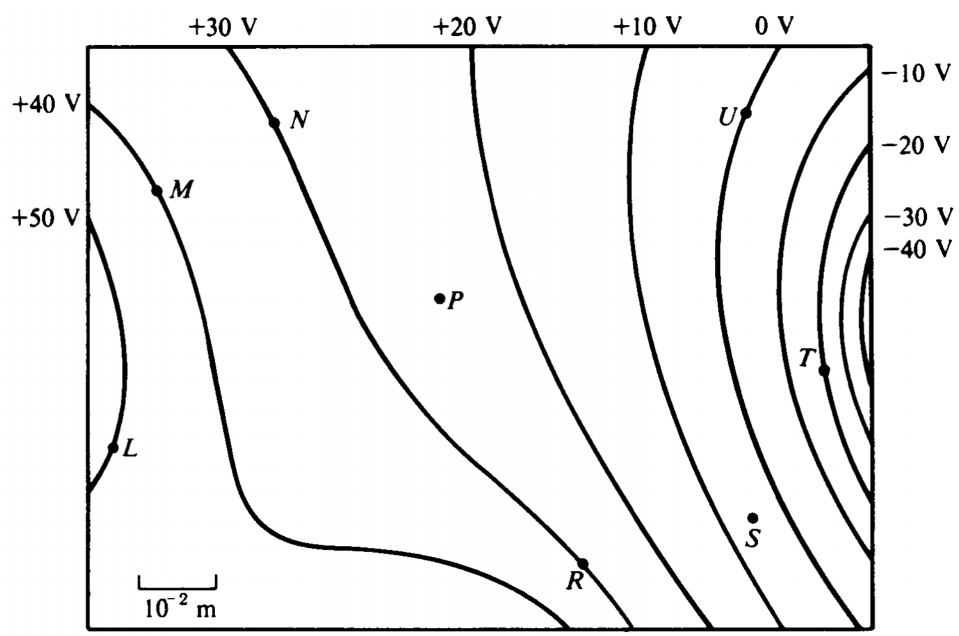
b. Determine the magnitude and direction of the force acting on the movable charge when it is located at the position x = *l*

c. Determine the work done <u>by the electric field</u> as the charge moves from infinity to the origin.



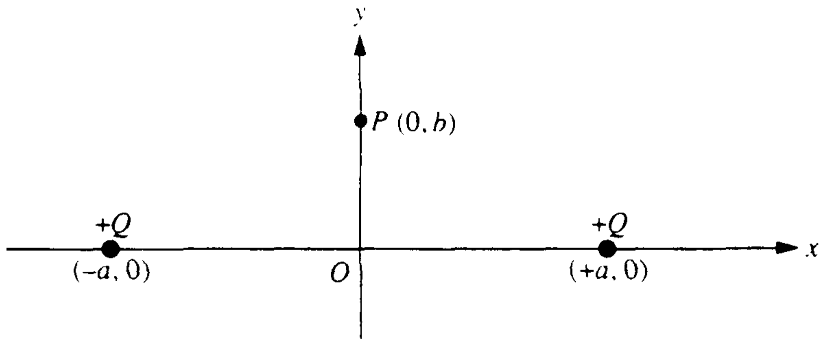
1982E1 (modified) Three point charges are arranged on the y–axis as shown above. The charges are +q at (0, a), –q at (0, 0), and +q at (0, –a). Any other charge or material is infinitely far away.

a. Determine the point(s) on the x–axis where the electric potential due to this system of charges is zero.
b. Determine the x and y components of the electric field at a point P on the x–axis at a distance x from the origin.



*1986E1. Three point charges produce the electric equipotential lines shown on the diagram above.

a. Draw arrows at points L, N. and U on the diagram to indicate the direction of the electric field at these points.
b. At which of the lettered points is the electric field E greatest in magnitude? Explain your reasoning.
c. Compute an approximate value for the magnitude of the electric field E at point P.
d. Compute an approximate value for the potential difference, $V_M - V_S$, between points M and S.
e. Determine the work done by the field if a charge of $+5 \times 10^{-12}$ coulomb is moved from point M to point R.
f. If the charge of $+5 \times 10^{-12}$ coulomb were moved from point M first to point S, and then to point R, would the answer to e. be different, and if so, how?

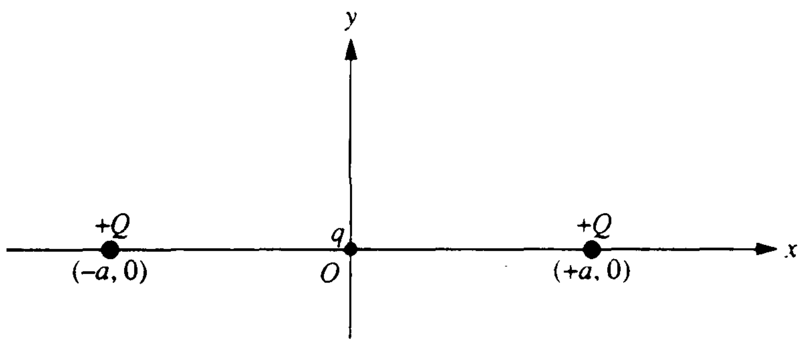


1991E1. Two equal positive charges Q are fixed on the x–axis. one at +a and the other at –a, as shown above. Point P is a point on the y–axis with coordinates (0, b). Determine each of the following in terms of the given quantities and fundamental constants.

a. The electric field E at the origin *O*.

b. The electric potential V at the origin *O*.

c. The magnitude of the electric field E at point *P*.



A small particle of charge q (q << Q) and mass m is placed at the origin, displaced slightly, and then released. Assume that the only subsequent forces acting are the electric forces from the two fixed charges Q. at x = +a and x = –a. and that the particle moves only in the xy –plane. In each of the following cases, describe briefly the motion of the charged particle after it is released. Write an expression for its speed when far away if the resulting force pushes it away from the origin.

d. q is positive and is displaced in the +x direction.

e. q is positive and is displaced in the +y direction.

f. q is negative and is displaced in the +y direction.

2000E2 (modified) Three particles, A, B, and C, have equal positive charges Q and are held in place at the vertices of an equilateral triangle with sides of length *l*, as shown in the figures below. The dotted lines represent the bisectors for each side. The base of the triangle lies on the x–axis, and the altitude of the triangle lies on the y–axis.

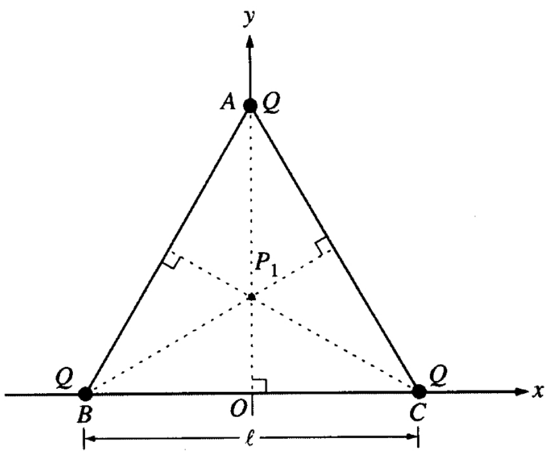


Figure 1

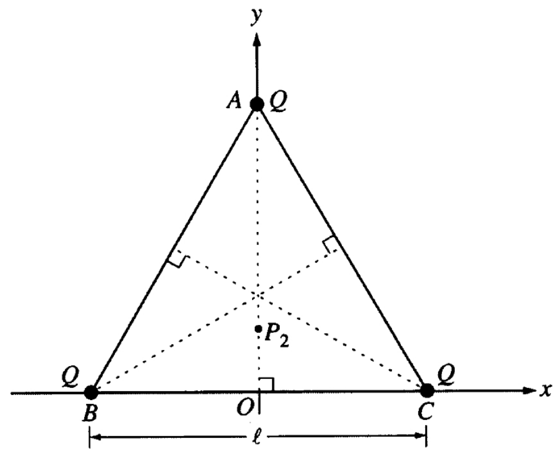


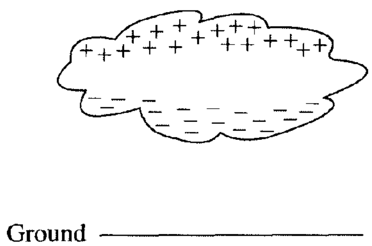
Figure 2

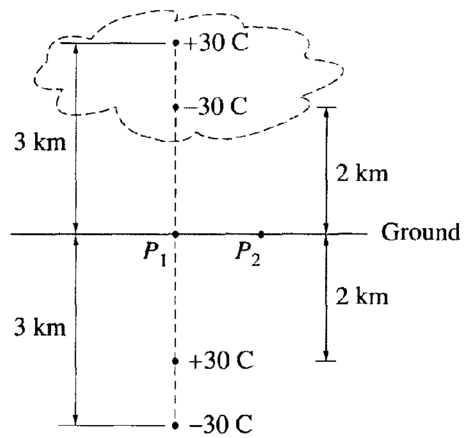
a. i. Point P_1, the intersection of the three bisectors, locates the geometric center of the triangle and is one point where the electric field is zero. On Figure 1 above, draw the electric field vectors E_A, E_B, and E_C at P, due to each of the three charges. Be sure your arrows are drawn to reflect the relative magnitude of the fields.

ii. Another point where the electric field is zero is point P_2 at $(0, y_2)$. On Figure 2 above, draw electric field vectors E_A, E_B, and E_C at P_2 due to each of the three point charges. Indicate below whether the magnitude of each of these vectors is greater than, less than, or the same as for point P_1.

	Greater than at P_1	Less than at P_1	The same as at P_1
E_A			
E_B			
E_C			

b. Explain why the x–component of the total electric field is zero at any point on the y–axis.
c. Write a general expression for the electric potential V at any point on the y–axis inside the triangle in terms of Q, *l*, and y.





Note: Figures not drawn to scale.

2001E1. A thundercloud has the charge distribution illustrated above left. Treat this distribution as two point charges, a negative charge of –30 C at a height of 2 km above ground and a positive charge of +30 C at a height of 3 km. The presence of these charges induces charges on the ground. Assuming the ground is a conductor, it can be shown that the induced charges can be treated as a charge of +30 C at a depth of 2 km below ground and a charge of –30 C at a depth of 3 km, as shown above right. Consider point P_1, which is just above the ground directly below the thundercloud, and point P_2, which is 1 km horizontally away from P_1.

a. Determine the direction and magnitude of the electric field at point P_1.

b. i. On the diagram, clearly indicate the direction of the electric field at point P_2

ii. How does the magnitude of the field at this point compare with the magnitude at point P_1? Justify your answer:

____ Greater ____Equal ____ Less

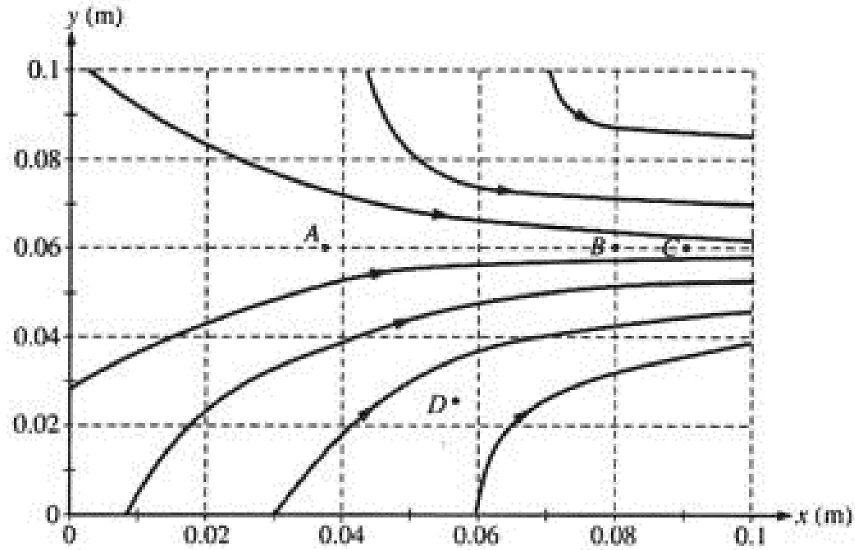
c. Letting the zero of potential be at infinity, determine the potential at these points.

i. Point P_1

ii. Point P_2

d. Determine the electric potential at an altitude of 1 km directly above point P_1.

e. Determine the total electric potential energy of this arrangement of charges.



*2005E1. Consider the electric field diagram above.

a. Points A, B, and C are all located at y = 0.06 m .

   i. At which of these three points is the magnitude of the electric field the greatest? Justify your answer.

   ii. At which of these three points is the electric potential the greatest? Justify your answer.

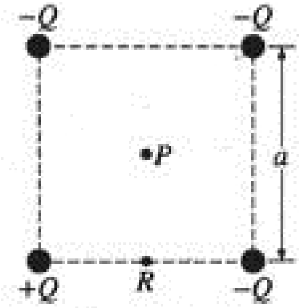
b. An electron is released from rest at point B.

   i. Qualitatively describe the electron's motion in terms of direction, speed, and acceleration.

   ii. Calculate the electron's speed after it has moved through a potential difference of 10 V.

c. Points B and C are separated by a potential difference of 20 V. Estimate the magnitude of the electric field midway between them and state any assumptions that you make.

d. On the diagram, draw an equipotential line that passes through point D and intersects at least three electric field lines.



2006E1. The square of side a above contains a positive point charge +Q fixed at the lower left corner and negative point charges –Q fixed at the other three corners of the square. Point P is located at the center of the square.

a. On the diagram, indicate with an arrow the direction of the net electric field at point P.

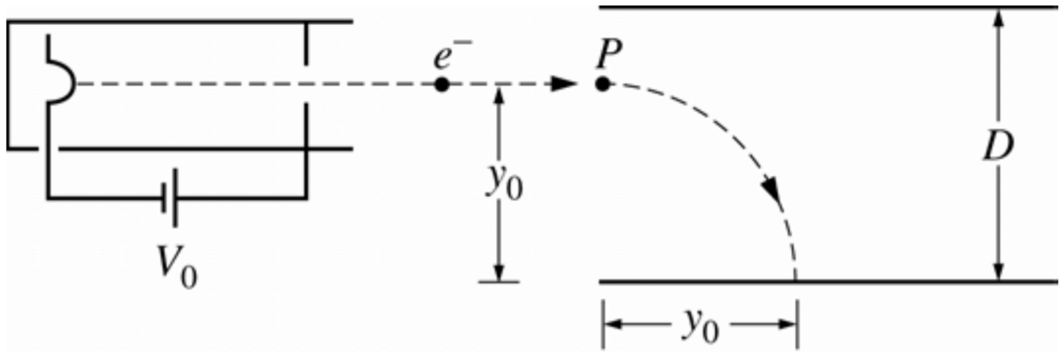
b. Derive expressions for each of the following in terms of the given quantities and fundamental constants.
   i. The magnitude of the electric field at point P
   ii. The electric potential at point P

c. A positive charge is placed at point P. It is then moved from point P to point R, which is at the midpoint of the bottom side of the square. As the charge is moved, is the work done on it by the electric field positive, negative, or zero?

   ____Positive ____Negative ____Zero

   Explain your reasoning.

d. i: Describe one way to replace a single charge in this configuration that would make the electric field at the center of the square equal to zero. Justify your answer.
   ii. Describe one way to replace a single charge in this configuration such that the electric potential at the center of the square is zero but the electric field is not zero. Justify your answer.



2009E2 (modified) Electrons created at the filament at the left end of the tube represented above are accelerated through a voltage V_0 and exit the tube. The electrons then move with constant speed to the right, as shown, before entering a region in which there is a uniform electric field between two parallel plates separated by a distance D. The electrons enter the field at point P, which is a distance y_0 from the bottom plate, and are deflected toward that plate. Express your answers to the following in terms of V_0, D, y_0, and fundamental constants.

a. Calculate the speed of the electrons as they exit the tube.

b. i. Calculate the magnitude of the electric field required to cause the electrons to land the distance y_0 from the edge of the plate.
ii. Indicate the direction of the electric field.

____ To the left ____ To the right

____ Toward the top of the page ____ Toward the bottom of the page

____ Into the page ____ Out of the page

Justify your answer.

c. Calculate the potential difference between the two plates required to produce the electric field determined in part b.

ANSWERS - AP Physics Multiple Choice Practice – Electrostatics

	Solution	Answer
1.	Since charge is free to move around on/in a conductor, excess charges will repel each other to the outer surface	D
2.	The net charge on the two spheres is +Q so when they touch and separate, the charge on each sphere (divided equally) is ½ Q. $F \propto Q_1Q_2$ so before contact $F \propto (2Q)(Q) = 2Q^2$ and after contact $F \propto (½ Q)(½ Q) = ¼ Q^2$ or 1/8 of the original force	D
3.	Newton's third law	B
4.	$F_g = Gm_1m_2/r^2$ and $F_E = kq_1q_2/r^2$. The nuclear force does not have a similar relationship.	A,B
5.	$F_E \propto q_1q_2/r^2$; if q_1 and $q_2 \times 2$; $F \times 4$ and if $r \div 2$, $F \times 4$ making the net effect $F \times 4 \times 4$	D
6.	By symmetry, the force on an electron at the center from the top half will be straight down and the force from the bottom half will also be straight down	B
7.	While spheres X and Y are in contact, electrons will repel away from the rod out of sphere X into sphere Y.	C
8.	While spheres 1 and 2 are in contact, electrons will repel away from the rod out of sphere 1 into sphere 2.	C
9.	The force vectors from the two +Q charges point down and to the left (away from the charges) so the resultant force points down and left	D
10.	The two vectors, each of magnitude F, point at right angles to each other so the resultant field is $\sqrt{2}F$	C
11.	$F_E = F_C$ and $q_1 = q_2 = e$ so we have $ke^2/R^2 = mv^2/R$ and we multiply both sides by ½ R so the right side becomes ½ mv^2 (the kinetic energy). Choices C and E could have been eliminated because they are negative, and kinetic energy cannot be negative. Choices A & D are dimensionally incorrect (D has the units of a force, not energy, and A has the units of electric potential)	A
12.	In I, charge separation occurs (negative charges repel to the leaves). The whole process describes charging by induction, where the electrons leave the electroscope to ground (the finger) and once contact with ground is broken, the electroscope is left with a positive charge (III)	D
13.	Charged objects attract object with an opposite charge, but also neutral objects by separation of charges.	B,C
14.	$F \propto 1/r^2$	A
15.	The distance between the +q charge and each charge is d. The force on the +q charge from each charge is in the same direction, making the net force $kq^2/d^2 + k(3q^2)/d^2$	B
16.	The rod will attract the same charge from each sphere to the side closer to the rod.	B
17.	$F \propto 1/r^2$; if $r \times 4$, $F \div 16$	D
18.	If the leaves are positive, further separation means they are becoming more positive, which implies electrons are leaving the leaves, attracted to the top plate of the electroscope. This will occur if the object is positively charged.	A
19.	Vector addition. Since all the charges are positive, the forces due to charges 2 and 4 point in opposite directions, making the magnitude of the net force along the x axis 2 N. Combine this with a net force along the y axis of 6 N using the Pythagorean theorem	A

20. If a positive rod attracts ball A, it is either negative or neutral. For ball B to also attract ball A means ball B can be charged positive or negative (if ball A is neutral) or neutral (if ball A is positive) D

21. $F \propto 1/r^2$; if r × 0.4 then F ÷ 0.4^2 A

22. The process described is charging by induction which gives the electroscope in this case a net negative charge. Bringing a negative charge near the top of the electroscope will cause electrons to repel to the leaves. Since the leaves are already negative, this will cause them to separate further. B

23. $F \propto 1/r^2$ A

24. Newton's third law requires the forces be equal and opposite. This eliminates choices A, B and C. Since they both positive, the force is repulsive. D

25. Only electrons are transferred in static charging processes. C

26. Any charge will experience a net force of zero where the electric field is zero. This must be where the fields from each charge point in opposite directions and also closer to the smaller charge, which is to the left of the +Q charge (the answer will be to the left of –1 m). Let the distances to the +Q and the –2Q charge be x and (X + 2), respectively. This gives $E_1 = E_2$ and $kQ/x^2 = k(2Q)/(x + 2)^2$. Solve for x and add the extra 1 m to the origin. A

27. $F \propto q_1q_2/r^2$; the original force $F \propto 100Q^2/d^2$. The new charges are 15Q and 5Q making the new force $F \propto 75Q^2/(2d)^2 = 19Q^2/d^2$ A

28. Assuming C remains constant and $U_C = ½ CV^2$, for U_C to double V must increase by $\sqrt{2}$ D

29. Initially, when B is removed, A and C are equally and oppositely charged and B is neutral. Touching B to A gives B ½ the charge of A (split equally). The charge on B is then ½ that of C and oppositely charged. When B and C touch, the total charge between them is ½ the charge of C and the same sign as C. Each sphere then has ¼ of the charge of C after contact is made. This makes the end result that the charge on sphere B is ¼ the original charge of A and the same sign as sphere C, which is opposite that of A C

30. $\Sigma F = 0$ so we have $T + k(q)(q)/d^2 - Mg = 0$ giving $T = Mg - kq^2/d^2$ D

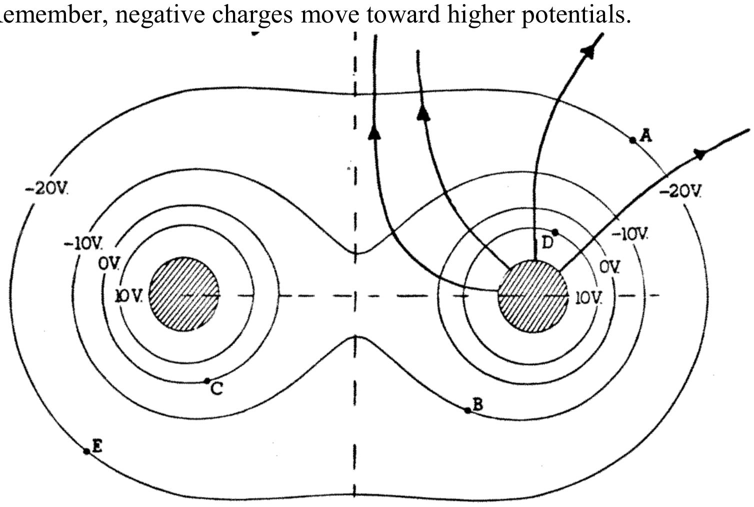
AP Physics Free Response Practice – Electrostatics – ANSWERS

WARNING: Only Electric Force is on AP Physics 1

1974B5

a. Since the potential increases as you near the cylinder on the right, it must also have a positive charge. Remember, negative charges move toward higher potentials.

b.



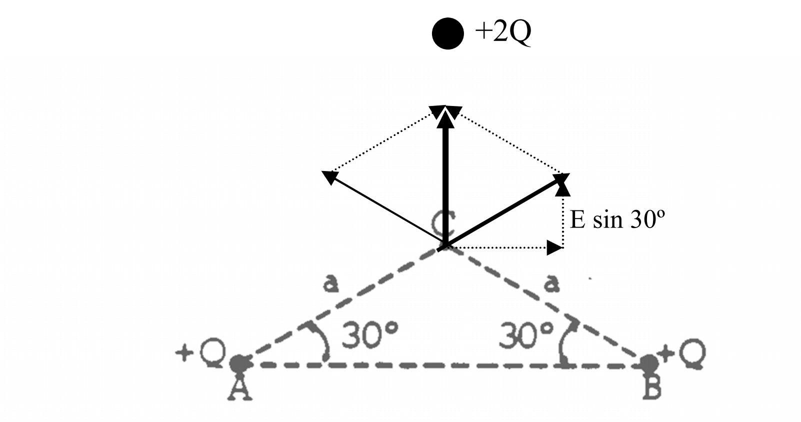
c. $V_A - V_B = (-20 \text{ V}) - (-10 \text{ V}) = -10 \text{ V}$

d. $W_{AED} = W_{AD} = -q\Delta V = -(0.5 \text{ C})(30 \text{ V}) = -15 \text{ J}$

1975B2

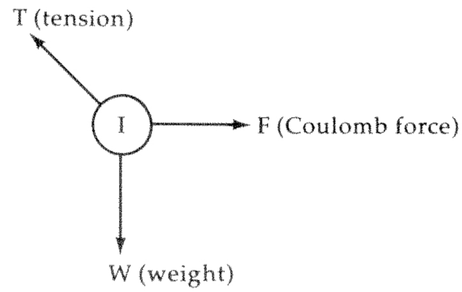
a. $V_C = kQ/a + kQ/a = 2kQ/a$; $W = -q\Delta V = -(+q)(V_\infty - V_C) = -q(0 - 2kQ/a) = 2kQq/a$

b. Looking at the diagram below, the fields due to the two point charges cancel their x components and add their y components, each of which has a value $(kQ/a^2) \sin 30^\circ = \frac{1}{2} kQ/a^2$ making the net E field (shown by the arrow pointing upward) $2 \times \frac{1}{2} kQ/a^2 = kQ/a^2$. For this field to be cancelled, we need a field of the same magnitude pointing downward. This means the positive charge +2Q must be placed directly above point C at a distance calculated by $k(2Q)/d^2 = kQ/a^2$ giving $d = \sqrt{2}a$



1979B7

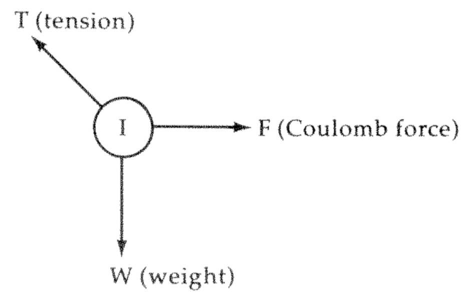
a.



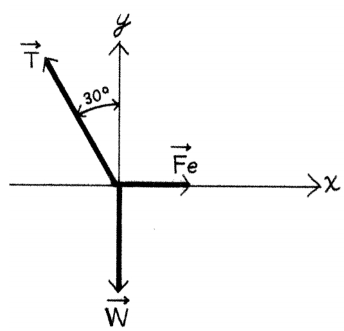
b. Resolving the tension into components we have T cos θ = W and T sin θ = F
where W = mg and $F = kq^2/r^2$ and $r = 2l \sin\theta$ giving $F = kq^2/(4l^2 \sin^2\theta)$
Dividing the two expressions we get $\tan\theta = F/mg = kq^2/(4l^2 \sin^2\theta\ mg)$
solving yields $q^2 = 4mgl^2 (\sin^2\theta)(\tan\theta)/k$

1981 B3

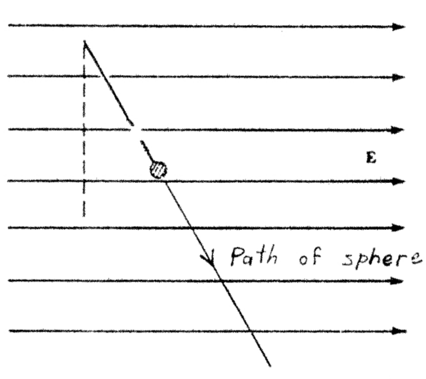
a.



b.



T cos 30º = mg so T = 0.058 N
$T \sin\theta = F_E = Eq$ gives $E = 5.8 \times 10^3$ N/C

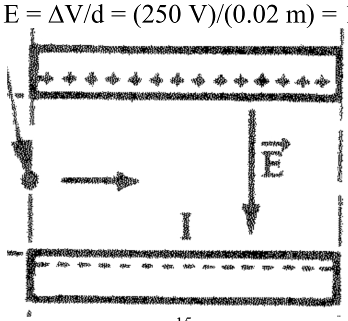


c. After the string is cut, the only forces are gravity, which acts down, and the electrical force which acts to the right. The resultant of these two forces causes a constant acceleration along the line of the string. The path is therefore down and to the right, along the direction of the string as shown above.

1985B3

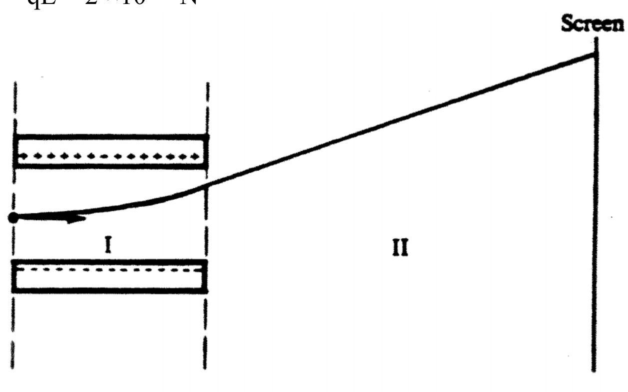
a. $K = (2 \times 10^3\ \text{eV})(1.6 \times 10^{-19}\ \text{J/eV}) = 3.2 \times 10^{16}\ \text{J}$
$K = \frac{1}{2} mv^2$ gives $v = 2.7 \times 10^7$ m/s

b. $E = \Delta V/d = (250\ \text{V})/(0.02\ \text{m}) = 1.25 \times 10^4$ V/m



c. $F = qE = 2 \times 10^{-15}$ N

d.



Path curves parabolically toward the upper plate in region I and moves in a straight line in region II.

1987B2

a. $V = kQ/r = 9 \times 10^4$ V

b. $W = q\Delta V$ (where V at infinity is zero) = 0.09 J

c. $F = kqQ/r^2 = 0.3$ N

d. Between the two charges, the fields from each charge point in opposite directions, making the resultant field the difference between the magnitudes of the individual fields.
$E = kQ/r^2$ gives $E_I = 1.2 \times 10^6$ N/C to the right and $E_{II} = 0.4 \times 10^6$ N/C to the left
The resultant field is therefore $E = E_I - E_{II} = 8 \times 10^5$ N/C to the right

e. From conservation of momentum $m_I v_I = m_{II} v_{II}$ and since the masses are equal we have $v_I = v_{II}$.
Conservation of energy gives $U = K = 2(\frac{1}{2} mv^2) = 0.09$ J giving v = 6 m/s

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1989B2

a. $E = kQ/r^2$ and since the field is zero $E_1 + E_2 = 0$ giving $k(Q_1/r_1^2 + Q_2/r_2^2) = 0$
This gives the magnitude of $Q_2 = Q_1(r_2^2/r_1^2) = 2\mu C$ and since the fields must point inopposite directions from each charge at point P, Q_2 must be negative.

b. $F = kQ_1Q_2/r^2 = 3.6$ N to the right (they attract)

c. $U = kQ_1Q_2/r = -0.72$ J

d. between the charges we have a distance from Q_1 of x and from Q_2 of (0.2 m – x)
$V = kQ_1.x + kQ_2/(0.2\ \text{m} - x) = 0$, solving for x gives x = 0.16 m

e. $W = q\Delta V$ where $\Delta V = V_\infty - V_R = 0$ so W = 0

1990B2

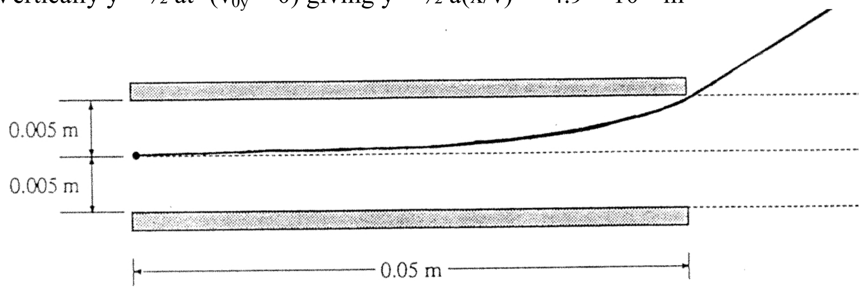
a. $E = V/d = 2 \times 10^4$ V/m

b. $F = Eq = ma$ gives $a = qE/m = 3.5 \times 10^{15}$ m/s^2

c. Horizontally: $x = vt$ giving $t = x/v$

Vertically $y = ½ at^2$ ($v_{0y} = 0$) giving $y = ½ a(x/v)^2 = 4.9 \times 10^{-3}$ m

d.

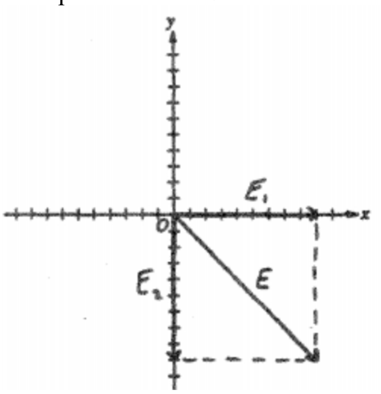


1993B2

a. i. $E = kq/r^2 = 9000$ N/C

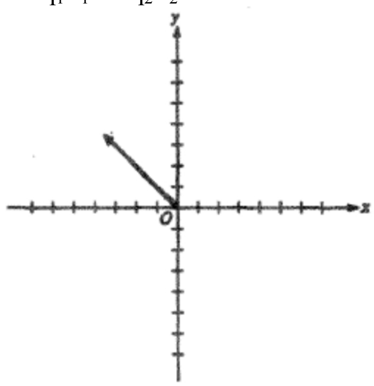
ii. $E = kq/r^2 = 9000$ N/C

iii.



b. $V = kq_1/r_1 + kq_2/r_2 = -9000$ V

c.



Since the charge is negative, the force acts opposite the direction of the net E field.

d. $W = q\Delta V = 0.036$ J

1996B6

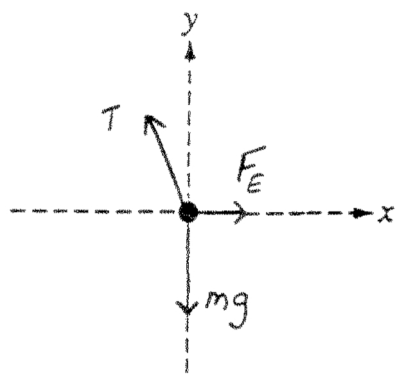
a. $\Sigma F = 0$ gives $qE = mg$ and $q = mg/E = 3.27 \times 10^{-19}$ C
b. The drop must have a net negative charge. The electric force on a negative charge acts opposite the direction of the electric field.
c. $V = Ed = 100$ V
d. The drop moves upward. The reduced mass decreases the downward force of gravity on the drop while if the charge remains the same, the upward electric force is unchanged.

2002B5B

a. Electric field lines point away from positive charges and toward negative charges. The plate on the left is negative and the plate on the right is positive.
b. $V = Ed = 100$ V
c. $C = \varepsilon_0 A/d = 1.3 \times 10^{-10}$ F
d. $F = qE = 8 \times 10^{-16}$ N to the right (opposite the direction of the electric field)
e. The potential difference between the center and one of the plates is 50 V.
$W = qV = ½ mv^2$ gives $v = 4.2 \times 10^6$ m/s

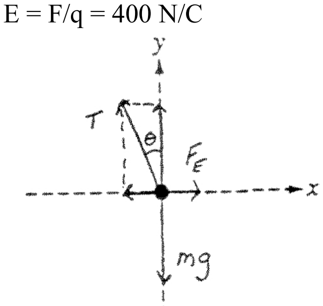
1998B2

a.



b. $E = F/q = 400$ N/C

c.



$T \sin\theta = F_E$ and $T \cos\theta = mg$. Dividing gives $\tan\theta = F/mg$ and $\theta = 18º$.
From the diagram $\sin\theta = x/(0.30 \text{ m})$ giving $x = 0.09$ m

d. i. $a_x = F/m = 3.2 \text{ m/s}^2$; $a_y = 9.8 \text{ m/s}^2$
$a = \sqrt{a_x^2 + a_y^2} = 10.3 \text{ m/s}^2$; $\tan\theta = (9.8 \text{ m/s}^2)/(3.2 \text{ m/s}^2) = 72º$ below the x axis
(or 18º to the right of the y axis, the same as the angle of the string)
ii. The ball moves in a straight line down and to the right

1999B2

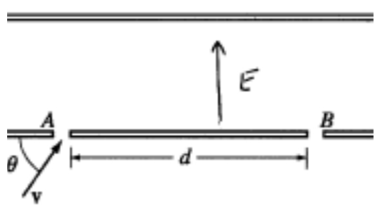
a. $W = qV = \frac{1}{2} mv^2$ gives $V = mv^2/2q = 1.0 \times 10^4$ V
b. Electrons travel toward higher potential making the upper plate at the higher potential.
c. i. $x = v_x t$ gives $t = 6.7 \times 10^{-10}$ s
   ii. $F = ma = qE$ and $E = V/d$ gives $a = qV/md$ and $y = \frac{1}{2} at^2$ ($v_{0y} = 0$) gives $y = qVt^2/2md = 6.5 \times 10^{-4}$ m
d. F_g is on the order of 10^{-30} N (mg) and $F_E = qE = qV/d$ is around 10^{-14} N so $F_E \gg F_g$
e. Since there is no more electric force, the path is a straight line.

2001B3

a. i. $V = \Sigma kQ/r = k(-Q/r + -Q/r + Q/r + Q/r) = 0$
   ii. The fields from the charges on opposing corners cancels which gives E = 0
b. i. $V = \Sigma kQ/r = k(-Q/r + -Q/r + Q/r + Q/r) = 0$
   ii. The field from each individual charge points along a diagonal, with an *x*-component to the right. The vertical components cancel in pairs, and the *x*-components are equal in magnitude. Each x component being $E = kQ/r^2 \cos 45^\circ$ and the distance from a corner to the center of $r^2 = s^2/2$ gives
   $E = 4E_x = 4\frac{kQ}{s^2/2}\frac{\sqrt{2}}{2} = 4\sqrt{2}kQ/s^2$
c. Arrangement 1. The force of attraction on the upper right charge is greater in arrangement 1 because the two closest charges are both positive, whereas in arrangement 2 one is positive and one is negative.

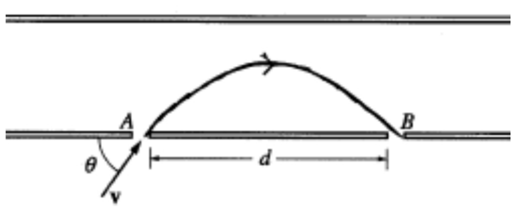
2003B4B

a. i.



   ii.

   iii.



b. $F = ma = qE$ gives $a = qE/m$
c. The acceleration is downward and at the top of the path, $v_y = v_{0y} - at = 0$ and $v_{0y} = v \sin\theta$ which gives $t_{top} = v \sin\theta/a$ or $t_{total} = 2t_{top} = 2v \sin\theta/a$ and substituting a from part b gives $t = (2mv \sin\theta)/qE$
d. $d = x_x t$ where $v_x = v \cos\theta$ giving $d = (2mv^2 \sin\theta \cos\theta)/qE$
e. The distance would be less because gravity, acting downward, will increase the electron's downward acceleration, decreasing the time spent in the field.

2005B3

a. $E = kq/r^2$ and the field from each charge points in opposite directions, with the larger field contribution pointing upward. $E_O = k(2q)/a^2 - kq/a^2 = kq/a^2$ upward (+y)

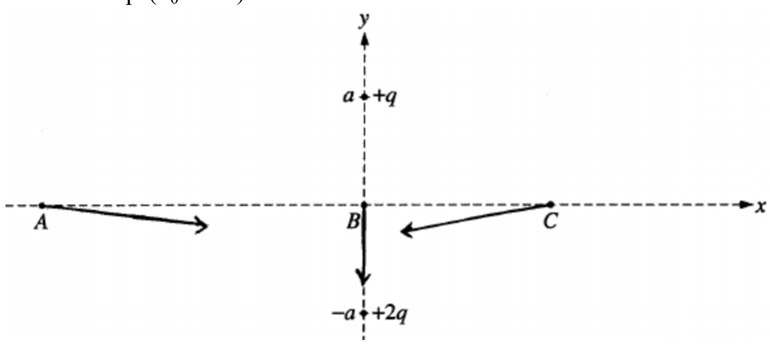
b. $V_O = \Sigma kq/r = k(2q)/a + kq/a = 3kq/a$

c. $F = kq_1q_2/r^2$ where in this case $r^2 = x_0^2 + a^2$

   i. $F = kq^2/(x_0^2 + a^2)$

   ii. $F = 2kq^2/(x_0^2 + a^2)$

d.



2005B3B

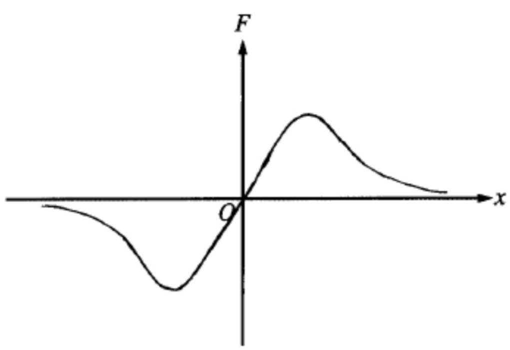
a. The distance between the charges is $r = \sqrt{a^2 + (2a)^2} = \sqrt{5}a$ The y components of the forces due to the two –2Q charges cancel so the magnitude of the net force equals the sum of the x components, where $F_x = F \cos\theta$ and $\cos\theta = 2a/r = 2/\sqrt{5}$

   Putting this all together gives $F_x = 2 \times (kQ(2Q)/r^2) \cos\theta = 8kQ^2/5\sqrt{5}a^2$ to the right (+x)

b. The contribution to the field from the –2Q charges cancel. This gives $E = kQ/(2a)^2 = kQ/4a^2$ to the right (+x)

c. $V = \Sigma kQ/r = k(-2Q)/a + k(-2Q)/a + k(-Q)/2a = -9kQ/2a$

d. At the origin the force is zero (they cancel). As the charge moves away from the origin, the force first increases as the x components grow, then decrease as the distance grows larger.



2006B3

a. Positive. The electric field due to q_1 points to the right since q_1 is negative. For the electric field to be zero at point P, the field form q_2 must point to the left, away from q_2 making q_2 positive.

b. $\mathbf{E}_1 + \mathbf{E}_2 = 0$ so setting the fields from each charge equal in magnitude gives $kq_1/d_1^2 = kq_2/d_2^2$, or $q_2 = q_1(d_2^2/d_1^2) = 4.8 \times 10^{-8}$ C

c. $F = kq_1q_2/r^2 = 1.4 \times 10^{-5}$ N to the left

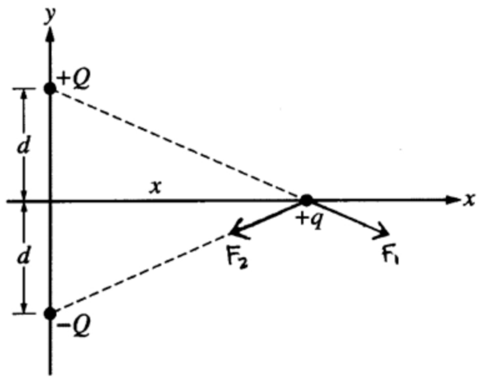
d. $V_1 + V_2 = 0 = kq_1/r_1 + kq_2/r_2$ and let $r_2 = d$ and $r_1 = (0.3\text{ m} - d)$

   solving yields d = 0.28 m to the left of q_2 which is at x = 0.20 m – 0.28 m = –0.08 m

e. $W = q\Delta V$ and since $\Delta V = 0$, $W = 0$

2006B3B

a.



b. The x components of the forces cancel so the net force is the sum of the y components, which are equal in magnitude and direction. $F_{net} = 2 \times F \cos\theta$ where θ is the angle between the y axis and the dashed line in the diagram above. $\cos\theta = d/r = d/\sqrt{x^2 + d^2}$
This gives $F_{net} = 2 \times kqQ/r^2 \times \cos\theta = 2kqQd/(x^2 + d^2)^{3/2}$

c. $E = F/q$ at the point where q_1 lies. $E = 2kQd/(x^2 + d^2)^{3/2}$

d. Since the charges Q and –Q are equidistant from the point and $V = \Sigma kQ/r$, the potential $V = 0$

e. As x gets large, the distance to the charges r and the value of x become similar, that is $\sqrt{x^2 + d^2} \approx x$.
Substituting this into the answer to b. yields $F = 2kqQd/x^3$

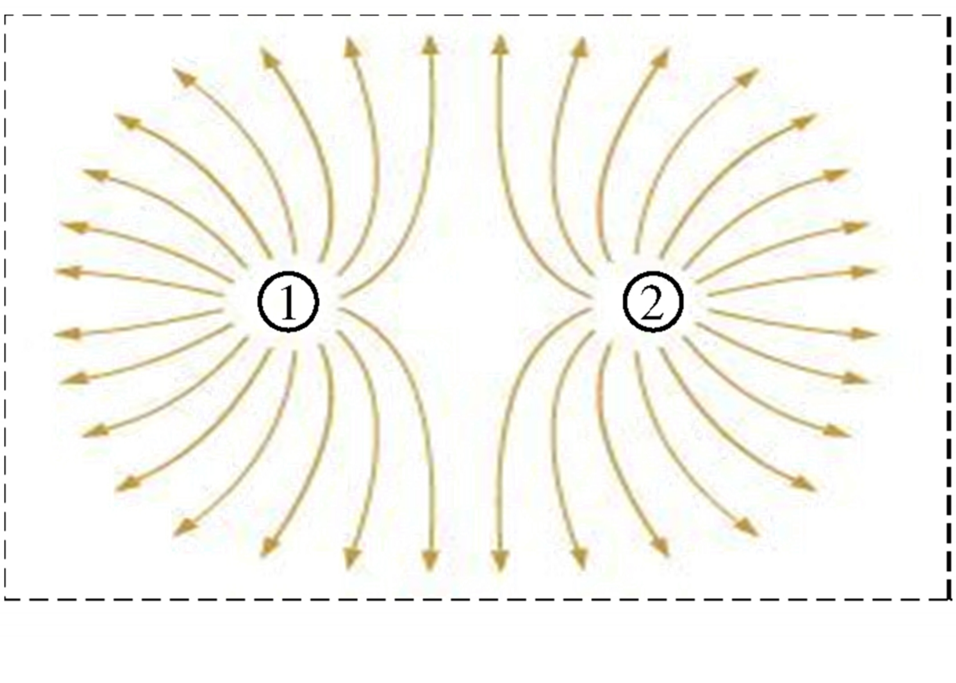
2009B2B

a. The x components of the forces due to the charges q_B cancel making the net force equal to the sum of the y components which are equal in magnitude and both point downward. The distance between q_A and either q_B is found by the Pythagorean theorem to be 0.05 m. $F_y = F \sin\theta$ where θ is the angle between the line joining q_A and q_B and the x axis, giving $\sin\theta = 3/5$.
This gives $F_{net} = 2 \times F_y = 2\,(kq_Aq_B/r^2) \times \sin\theta = 2.6 \times 10^{-7}$ N down (–y)

b. Particle A will accelerate downward, but as the particle approaches the origin, the force and the acceleration will decrease to zero at the origin. It will then pass through the origin, with a net force now pointing upward, where it will eventually slow down and reverse direction, repeating the process. The short answer is the particle will oscillate vertically about the origin.

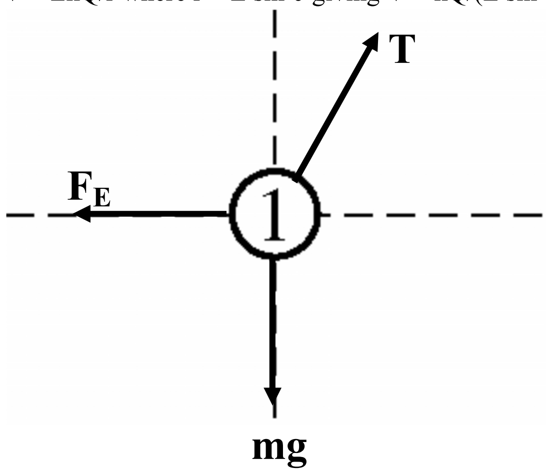
2009B2

a.



b. $V = \Sigma kQ/r$ where $r = L \sin\theta$ giving $V = kQ/(L \sin\theta) + kQ/(L \sin\theta) = 2kQ/(L \sin\theta)$

c.



d. $\Sigma F_y = 0$; $T \cos\theta = mg$

$\Sigma F_x = 0$; $T \sin\theta = F_E = kQ^2/(2L \sin\theta)^2$

1974E2

a. $E = V/d = V/b$

b. $C = \varepsilon_0 A/d = \varepsilon_0 A/b$; $Q = CV = \varepsilon_0 AV/b$

c. This arrangement acts as two capacitors in series, which each have a potential difference ½ V. Using $E = V/d$ where $d = ½(b - a)$ for each of the spaces above and below. This gives $E = V/d = (½\ V)/½(b - a) = V/(b - a)$

d. With the copper inserted, we have two capacitors in series, each with a spacing $½(b - a)$. The capacitance of each is then $\varepsilon_0 A/(½(b - a))$ and in series, two equal capacitors have an equivalent capacitance of ½ C makinf the total capacitance with the copper inserted $½\varepsilon_0 A/(½(b - a)) = \varepsilon_0 A/(b - a)$ making the ratio $b/(b - a)$. Notice the final capacitance is effectively a new single capacitor with an air gap of $(b - a)$. Imagine sliding the copper slab up to touch the top plate, this is the same result. This is why adding capacitors in series decreases the capacitance as if the gap between the plates was increased.

1975E1

a. To find V along the x axis we use $V = \Sigma kq/r$ where $r = \sqrt{l^2 + x^2}$ giving $V = 2kq/\sqrt{l^2 + x^2}$ and $U_E = qV$ so as a function of x we have $U_E = 2kq^2/\sqrt{l^2 + x^2}$

b. Along the x axis, the y components of the forces cancel and the net force is then the sum of the x components of the forces. Since x = l in this case, the forces make an angle of 45º to the x axis and we have $F = 2 \times F_x = 2 \times F \times \cos 45º = 2 \times kq^2/(\sqrt{l^2 + l^2})^2 \times \cos 45º = kq^2/\sqrt{2}l^2$

c. At the origin, the potential is $V = kq/l + kq/l = 2kq/l$ and with $V_\infty = 0$ we have $W = -q\Delta V = -2kq^2/l$

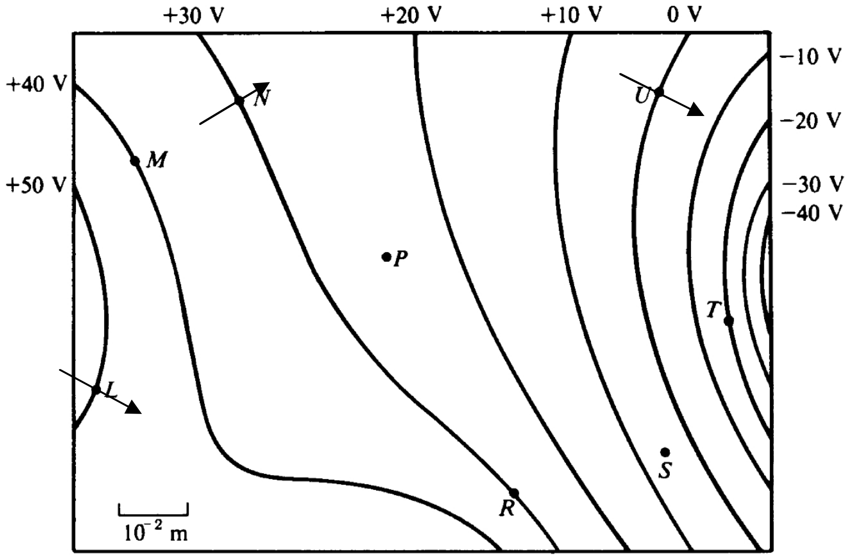
1982E1

a. $V = \Sigma kq/r = -kq/x + 2kq/\sqrt{a^2 + x^2} = 0$ which gives $1/x = 2/\sqrt{a^2 + x^2}$ cross multiplying and squaring gives $4x^2 = a^2 + x^2$ yielding $x = \pm a/\sqrt{3}$

b. $E = kq/r^2$ and by symmetry, the y components cancel. The x components of the electric field from the positive charges points to the right and has magnitude $(kq/r^2) \cos\theta$ where $\cos\theta = x/r = x/\sqrt{x^2 + a^2}$ and the x component of the electric field from the –q charge points to the left with magnitude kq/x^2 making the net field
$E = 2kqx/(x^2 + a^2)^{3/2} - kq/x^2$

1986E1

a.



The field lines point perpendicular to the equipotential lines from high to low potential.

b. The magnitude of the field is greatest at point T because the equipotential lines are closest together, meaning ΔV has the largest gradient, which is related to the strength of the electric field.

c. $E = \Delta V/d = (10 \text{ V})/(0.02 \text{ m}) = 500 \text{ V/m}$

d. $V_M - V_S = 40 \text{ V} - 5 \text{ V} = 35 \text{ V}$

e. $W = -q\Delta V$ and $\Delta V = -10$ V which gives $W = 5 \times 10^{-11}$ J

f. The work done is independent of the path so the answer would be the same.

1991E1

a. $E = kQ/a^2$ for each charge, but each vector points in the opposite direction so E = 0

b. $V = kQ/a + kQ/a = 2kQ/a$

c. the distance to point P from either charge is $r = \sqrt{a^2 + b^2}$ and the magnitude of E is $kQ/r^2 = kQ/(a^2 + b^2)$
The x components cancel so we have only the y components which are $E \sin\theta$ where $\sin\theta = b/\sqrt{a^2 + b^2}$ and adding the 2 y components from the two charges gives $E_{net} = 2kQb/(a^2 + b^2)^{3/2}$

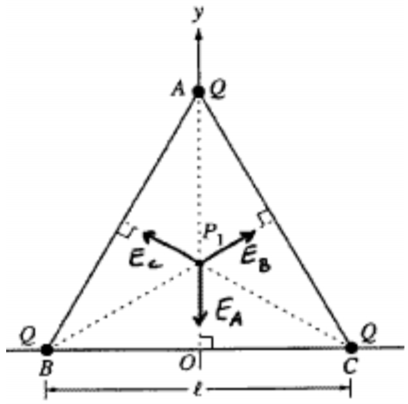
d. The particle will be pushed back toward the origin and oscillate left and right about the origin.

e. The particle will accelerate away from the origin.
The potential of at the center is $2kQ/a$ and far away $V_\infty = 0$. To find the speed when far away we use $W = q\Delta V = K = \frac{1}{2} mv^2$ which gives $v = 2\sqrt{\frac{kQq}{ma}}$

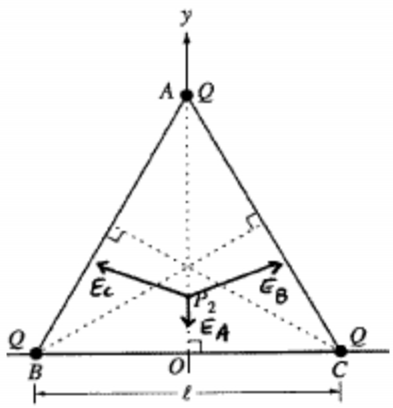
f. The particle will be pulled back toward the origin and oscillate up and down around the origin.

2000E2

a. i.



ii.



	Greater than at P_1	Less than at P_1	The same as at P_1
E_A		✓	
E_B	✓		
E_C	✓		

b. The x components cancel due to the symmetry about the y axis.

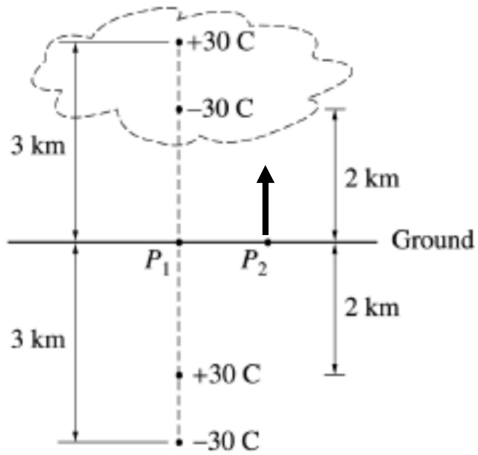
c. $V = \Sigma kQ/r = kQ_A/r_A + kQ_B/r_B + kQ_C/r_C$ where the terms for B and C are equal so we have $V = kQ_A/r_A + 2Q/r_B$

and using the proper geometry for the distances gives $V = k\left|\frac{Q}{\frac{\sqrt{3}l}{2}-y} + \frac{2Q}{\sqrt{\frac{l^2}{4}+y^2}}\right|$

2001E1

a. E is the vector sum of kQ/r^2. Let fields directed upward be positive and fields directed downward be negative. This gives $E = k[-30\ C/(3000\ m)^2 + 30\ C/(2000\ m)^2 + 30\ C/(2000\ m)^2 - 30\ C/(3000\ m)^2] = 75{,}000$ N/C upward

b. i.



ii. Because it is a larger distance from the charges, the magnitude is less.

c. i. By symmetry, the potentials cancel and V = 0

ii. By symmetry, the potentials cancel and V = 0

d. $V = \Sigma kQ/r = k[30\ C/(2000\ m) - 30\ C/(1000\ m) + 30\ C/(3000\ m) - 30\ C/(4000\ m)] = -1.12 \times 10^8$ V

e. $U = kq_1q_2/r$ for *each pair* of charges
$= k[(30)(-30)/1000 + (30)(30)/5000 + (30)(-30)/6000 + -30(30)/4000 + -30(-30)/5000 + 30(-30)/1000] =$
-1.6×10^{10} J

2005E1

a. i. The magnitude of the field is greatest at point C because this is where the field lines are closest together.

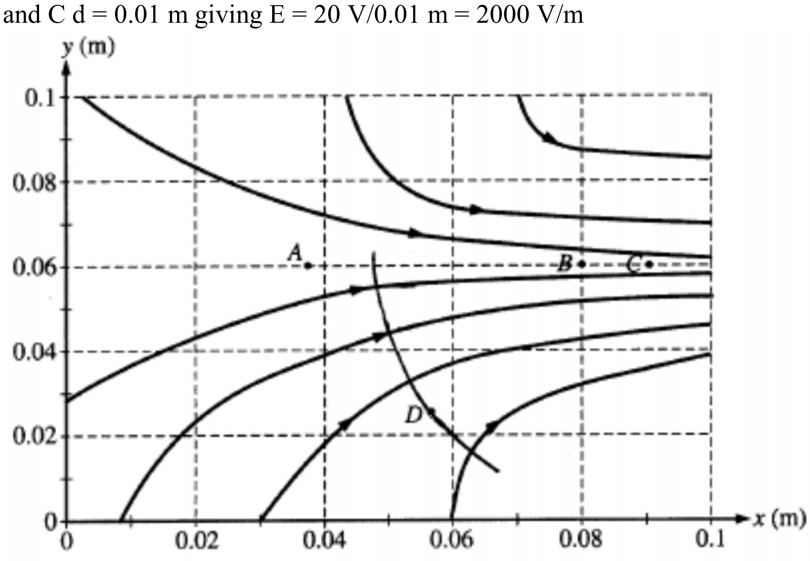
ii. The potential is greatest at point A. Electric field lines point from high to low potential.

b. i. The electron moves to the left, against the field lines. As the field gets weaker the electron's acceleration to the left decreases in magnitude, all the while gaining speed to the left.

ii. $W = q\Delta V = \frac{1}{2} mv^2$ gives $v = 1.9 \times 10^6$ m/s

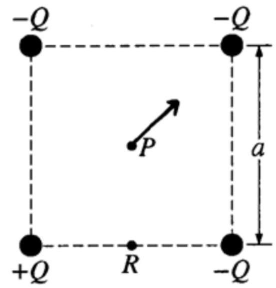
c. If we assume the field is nearly uniform between B and C we can use $E = \Delta V/d$ where the distance between B and C d = 0.01 m giving E = 20 V/0.01 m = 2000 V/m

d.



2006E1

a.



b. i. The fields at point *P* due to the upper left and lower right negative charges are equal in magnitude and opposite in direction so they sum to zero. The fields at point *P* due to the other two charges are equal in magnitude and in the same direction so they add.
Using $r^2 = a^2/2$ we have $E = 2 \times kQ/r^2 = 4kQ/a^2$
ii. $V = \Sigma kQ/r = k(-Q - Q - Q + Q)/r = -2kQ/r$ with $r = a/\sqrt{2}$ giving $V = -2\sqrt{2}kQ/a$

c. Negative. The field is directed generally from *R* to *P* and the charge moves in the opposite direction. Thus, the field does negative work on the charge.

d. i. Replace the top right negative charge with a positive charge OR replace the bottom left positive charge with a negative charge. The vector fields/forces all cancel from oppositely located same charge pairs.
ii. Replace the top left negative charge with a positive charge OR replace the bottom right negative charge with a positive charge. The scalar potentials all cancel from equidistant located opposite charge pairs. The field vectors in these cases will not cancel.

2009E2

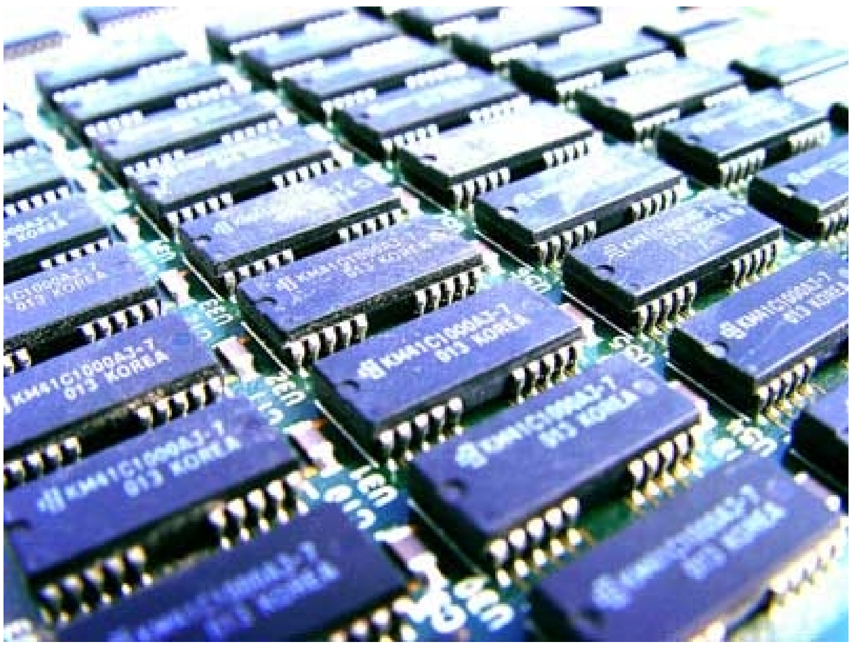
a. $W = qV_0 = \frac{1}{2} mv^2$ giving $v = \sqrt{\frac{2eV_0}{m}}$

b. i. The time to travel horizontally a distance y_0 is found from $v = d/t$ giving $t = d/v = y_0/\sqrt{\frac{2eV_0}{m}}$
The downward acceleration of the electron is found from $F = qE = ma$ giving $a = eE/m$ and using $y = \frac{1}{2} at^2$ and substituting the values found earlier we have $y = y_0 = \frac{1}{2} (eE/m)(y_0^2)/(2eV_0/m)$ which yields $E = 4V_0/y_0$
ii. For the electron to accelerate downward requires the electric field to point upward, toward the top of the page since negative charges experience forces opposite electric field lines.

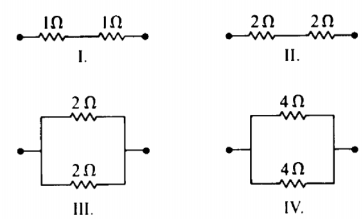
c. $\Delta V = ED = (4D/y_0)V_0$

Chapter 11

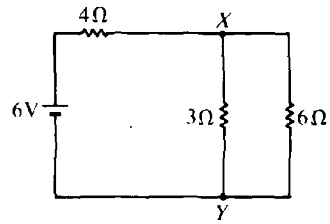
Circuits



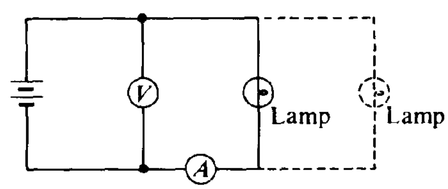
AP Physics Multiple Choice Practice – Circuits



1. **Multiple Correct.** Which two arrangements of resistors shown above have the same resistance between the terminals? Select two answers:
(A) I
(B) II
(C) III
(D) IV

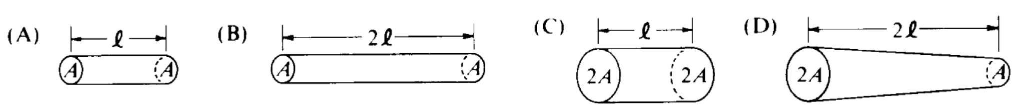


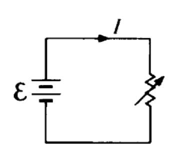
2. In the circuit shown above, what is the value of the potential difference between points X and Y if the 6–volt battery has no internal resistance?
(A) 2 V (B) 3 V (C) 4 V (D) 6V

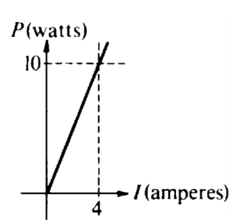


3. A lamp, a voltmeter V, an ammeter A, and a battery with zero internal resistance are connected as shown above. Connecting another lamp in parallel with the first lamp as shown by the dashed lines would
(A) increase the ammeter reading (B) decrease the ammeter reading
(C) increase the voltmeter reading (D) decrease the voltmeter reading

4. The five resistors shown below have the lengths and cross–sectional areas indicated and are made of material with the same resistivity. Which has the greatest resistance?

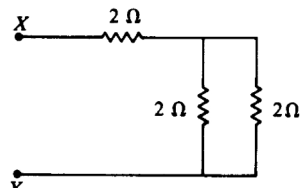






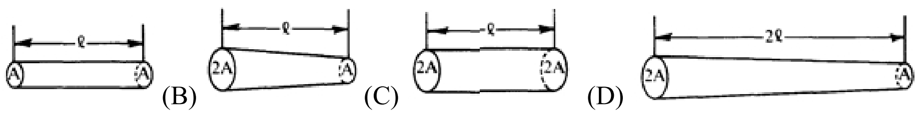
5. The circuit shown above left is made up of a variable resistor and a battery with negligible internal resistance. A graph of the power P dissipated in the resistor as a function of the current I supplied by the battery is given above right. What is the emf of the battery?
(A) 0.025 V (B) 2.5 V (C) 6.25 V (D) 40 V

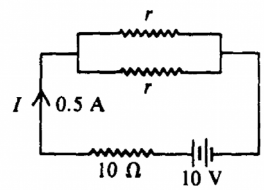
6. An immersion heater of resistance R converts electrical energy into thermal energy that is transferred to the liquid in which the heater is immersed. If the current in the heater is I, the thermal energy transferred to the liquid in time t is
(A) IRt (B) I^2Rt (C) IRt^2 (D) IR/t



7. The total equivalent resistance between points X and Y in the circuit shown above is
(A) 3 Ω (B) 4 Ω (C) 5 Ω (D) 6 Ω

8. The five resistors shown below have the lengths and cross–sectional areas indicated and are made of material with the same resistivity. Which resistor has the least resistance?

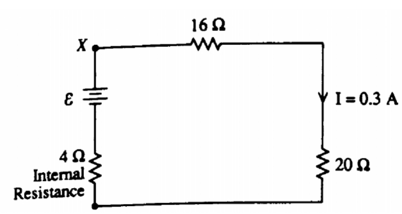




9. In the circuit shown above, the value of r for which the current I is 0.5 ampere is
(A) 1 Ω (B) 5 Ω (C) 10 Ω (D) 20 Ω

10. Kirchhoff's loop rule for circuit analysis is an expression of which of the following?
(A) Conservation of charge (B) Conservation of energy (C) Ampere's law
(D) Ohm's law

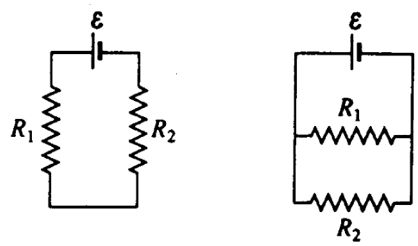
<u>Questions 11-12</u>



The above circuit diagram shows a battery with an internal resistance of 4.0 ohms connected to a 16–ohm and a 20–ohm resistor in series. The current in the 20–ohm resistor is 0.3 amperes

11. What is the emf of the battery?
(A) 1.2 V (B) 6.0 V (C) 10.8 V (D) 12.0 V

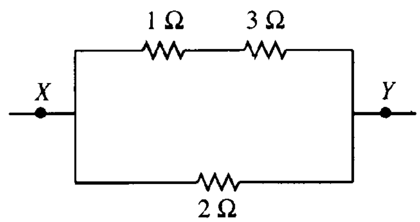
12. What power is dissipated by the 4–ohm internal resistance of the battery?
(A) 0.36 W (B) 1.2 W (C) 3.2 W (D) 3.6 W



Series Connection **Parallel Connection**

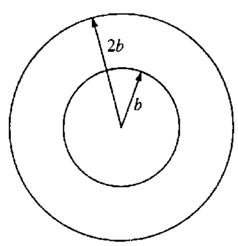
13. In the diagrams above, resistors R_1 and R_2 are shown in two different connections to the same source of emf ε that has no internal resistance. How does the power dissipated by the resistors in these two cases compare?
(A) It is greater for the series connection.
(B) It is greater for the parallel connection.
(C) It is different for each connection, but one must know the values of R_1 and R_2 to know which is greater.
(D) It is different for each connection, but one must know the value of ε to know which is greater.

<u>Questions 14-15</u> refer to the following diagram that shows part of a closed electrical circuit.



14. The electrical resistance of the part of the circuit shown between point X and point Y is
(A) 4/3 Ω (B) 2 Ω (C) 4 Ω (D) 6 Ω

15. When there is a steady current in the circuit, the amount of charge passing a point per unit of time is
(A) the same everywhere in the circuit
(B) greater in the 1 Ω resistor than in the 2 Ω resistor
(C) greater at point X than at point Y
(D) greater in the 2 Ω resistor than in the 3 Ω resistor

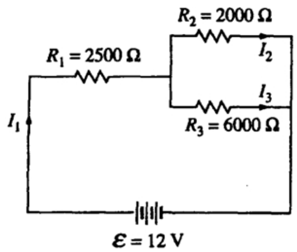


16. Two concentric circular loops of radii b and $2b$, made of the same type of wire, lie in the plane of the page, as shown above. The total resistance of the wire loop of radius b is R. What is the resistance of the wire loop of radius $2b$?
(A) $R/4$ (B) $R/2$ (C) $2R$ (D) $4R$

17. A wire of length L and radius r has a resistance R. What is the resistance of a second wire made from the same material that has a length $L/2$ and a radius $r/2$?
(A) $4R$ (B) $2R$ (C) R (D) $R/4$

18. The operating efficiency of a 0.5 A, 120 V electric motor that lifts a 9 kg mass against gravity at an average velocity of 0.5 m/s is most nearly
(A) 13% (B) 25% (C) 53% (D) 75 %

Questions 19-20

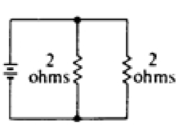


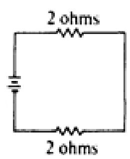
19. What is the current I_1?
(A) 1.0 mA (B) 2.0 mA (C) 3.0 mA (D) 6.0 mA

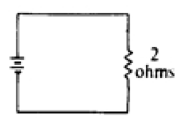
20. How do the currents I_1, I_2, and I_3 compare?
(A) $I_1 > I_2 > I_3$ (B) $I_1 > I_3 > I_2$ (C) $I_2 > I_1 > I_3$ (D) $I_3 > I_1 > I_2$

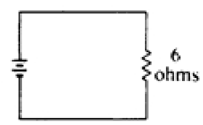
21. When lighted, a 100–watt light bulb operating on a 110–volt household circuit has a resistance closest to
(A) $10^{-2}\ \Omega$ (B) $10^{-1}\ \Omega$ (C) $10\ \Omega$ (D) $100\ \Omega$

Questions 22-24

(A) 

(B) 

(C) 

(D) 

The batteries in each of the circuits shown above are identical and the wires have negligible resistance.

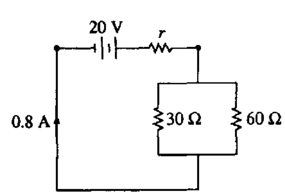
22. In which circuit is the current furnished by the battery the greatest?
(A) A (B) B (C) C (D) D

23. In which circuit is the equivalent resistance connected to the battery the greatest?
(A) A (B) B (C) C (D) D

24. Which circuit dissipates the least power?
(A) A (B) B (C) C (D) D

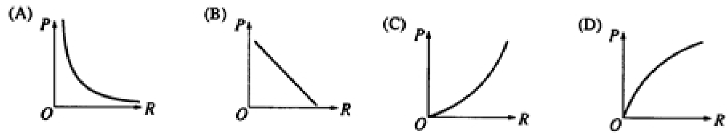
25. The power dissipated in a wire carrying a constant electric current I may be written as a function of the length l of the wire, the diameter d of the wire, and the resistivity ρ of the material in the wire. In this expression, the power dissipated is directly proportional to which of the following?
(A) l only (B) d only (C) l and ρ only (D) d and ρ only

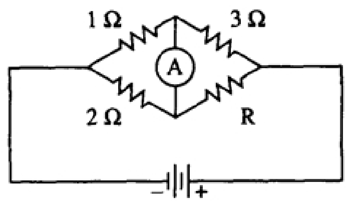
26. A wire of resistance R dissipates power P when a current I passes through it. The wire is replaced by another wire with resistance $3R$. The power dissipated by the new wire when the same current passes through it is
(A) P/9 (B) P/3 (C) 3P (D) 6P



27. A 30–ohm resistor and a 60–ohm resistor are connected as shown above to a battery of emf 20 volts and internal resistance r. The current in the circuit is 0.8 ampere. What is the value of r?
(A) 0.22 Ω (B) 4.5 Ω (C) 5 Ω (D) 16Ω

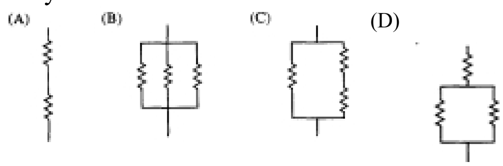
28. A variable resistor is connected across a constant voltage source. Which of the following graphs represents the power P dissipated by the resistor as a function of its resistance R?



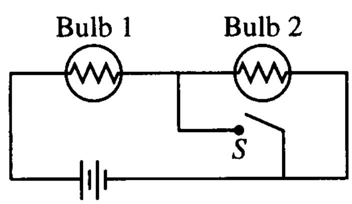


29. If the ammeter in the circuit above reads zero, what is the resistance R ?
(A) 1.5 Ω (B) 4 Ω (C) 5 Ω (D) 6Ω

30 Which of the following combinations of 4Ω resistors would dissipate 24 W when connected to a 12 Volt battery?



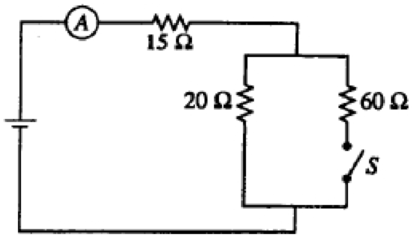
31. A narrow beam of protons produces a current of 1.6×10^{-3} A. There are 10^{9} protons in each meter along the beam. Of the following, which is the best estimate of the average speed of the protons in the beam?
(A) 10^{-15} m/s (B) 10^{-12} m/s (C) 10^{-7} m/s (D) 10^{7} m/s



32. The circuit in the figure above contains two identical lightbulbs in series with a battery. At first both bulbs glow with equal brightness. When switch S is closed, which of the following occurs to the bulbs?

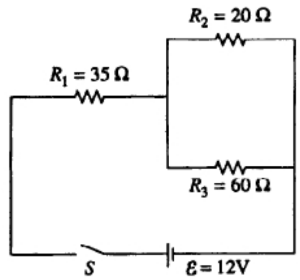
	Bulb I	Bulb 2
(A)	Goes out	Gets brighter
(B)	Gets brighter	Goes out
(C)	Gets brighter	Gets slightly dimmer
(D)	Gets slightly dimmer	Gets brighter

33. A hair dryer is rated as 1200 W, 120 V. Its effective internal resistance is
(A) 0.1 Ω (B) 10 Ω (C) 12 Ω (D) 120 Ω



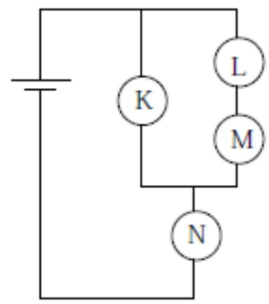
34. When the switch S is open in the circuit shown, the reading on the ammeter A is 2.0 A. When the switch is closed, the reading on the ammeter is
(A) doubled
(B) increased slightly but not doubled
(C) decreased slightly but not halved
(D) halved

35. Two conducting cylindrical wires are made out of the same material. Wire X has twice the length and twice the diameter of wire Y. What is the ratio R_x/R_y of their resistances?
(A) ½ (B) 1 (C) 2 (D) 4



36. In the circuit shown above, the equivalent resistance of the three resistors is
(A) 15Ω (B) 20 Ω (C) 50 Ω (D) 115 Ω

<u>Questions 37-40</u>



Four identical light bulbs K, L, M, and N are connected in the electrical circuit shown above.

37. Rank the current through the bulbs.
(A) L = M > K = N
(B) L > M > K > N
(C) N > K > L = M
(D) N > L = M > K

38. In order of decreasing brightness (starting with the brightest), the bulbs are:
(A) L = M > K = N
(B) L > M > K > N
(C) N > K > L = M
(D) N > L = M > K

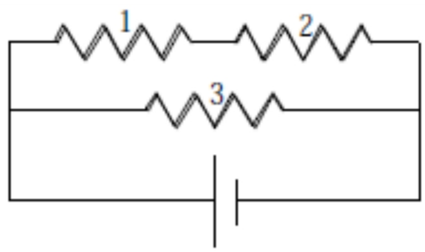
39. Bulb K burns out. Which of the following statements is true?
(A) All the light bulbs go out.
(B) Bulb N becomes brighter.
(C) The brightness of bulb N remains the same.
(D) Bulb N becomes dimmer but does not go out.

40. Bulb M burns out. Which of the following statements is true?
(A) All the light bulbs go out.
(B) Bulb N goes out but at least one other bulb remains lit.
(C) The brightness of bulb N remains the same.
(D) Bulb N becomes dimmer but does not go out.

41. When two resistors, having resistance R_1 and R_2, are connected in parallel, the equivalent resistance of the combination is 5 Ω. Which of the following statements about the resistances is correct?
(A) Both R_1 and R_2 are greater than 5 Ω.
(B) Both R_1 and R_2 are equal to 5 Ω.
(C) Both R_1 and R_2 are less than 5 Ω.
(D) One of the resistances is greater than 5 Ω, one of the resistances is less than 5 Ω.

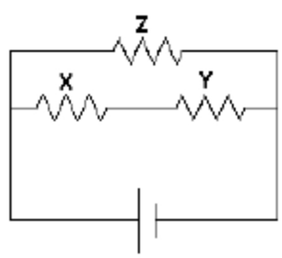
42. Three resistors – R_1, R_2, and R_3 – are connected in series to a battery. Suppose R_1 carries a current of 2.0 A, R_2 has a resistance of 3.0 Ω, and R_3 dissipates 6.0 W of power. What is the voltage across R_3?
(A) 1.0 V (B) 3.0 V (C) 6.0 V (D) 12 V

43. When a single resistor is connected to a battery, a total power P is dissipated in the circuit. How much total power is dissipated in a circuit if n identical resistors are connected in series using the same battery? Assume the internal resistance of the battery is zero.
(A) n^2P (B) nP (C) P (D) P/n



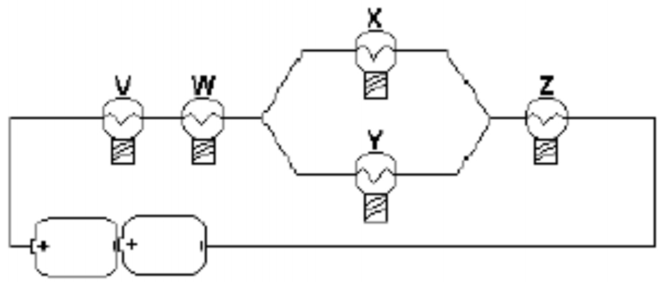
44. Consider the compound circuit shown above. The three bulbs 1, 2, and 3 – represented as resistors in the diagram – are identical. Which of the following statements are true? Select two correct answers.
(A) Bulb 3 is brighter than bulb 1 or 2.
(B) Bulb 3 has more current passing through it than bulb 1 or 2.
(C) Bulb 3 has the same voltage drop across it than bulb 1.
(D) Bulb 3 has the same voltage drop across it than bulb 2.

45. Wire I and wire II are made of the same material. Wire II has twice the diameter and twice the length of wire I. If wire I has resistance R, wire II has resistance
(A) $R/8$ (B) $R/4$ (C) $R/2$ (D) R



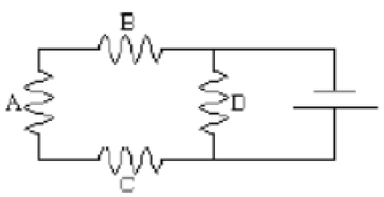
46. Given the simple electrical circuit above, if the current in all three resistors is equal, which of the following statements must be true?
(A) X, Y, and Z all have equal resistance
(B) X and Y have equal resistance
(C) X and Y added together have the same resistance as Z
(D) X and Y each have more resistance than Z

47. Wire Y is made of the same material but has twice the diameter and half the length of wire X. If wire X has a resistance of R then wire Y would have a resistance of
(A) $R/8$ (B) R (C) $2R$ (D) $8R$



48. The diagram above represents a simple electric circuit composed of 5 identical light bulbs and 2 flashlight cells. Which bulb (or bulbs) would you expect to be the brightest?
(A) V only
(B) V and W only
(C) V and Z only
(D) V, W and Z only

49. Three different resistors R_1, R_2 and R_3 are connected in parallel to a battery. Suppose R_1 has 2 V across it, $R_2 = 4\ \Omega$, and R_3 dissipates 6 W. What is the current in R_3?
(A) 0.5 A (B) 2 A (C) 3 A (D) 12 A

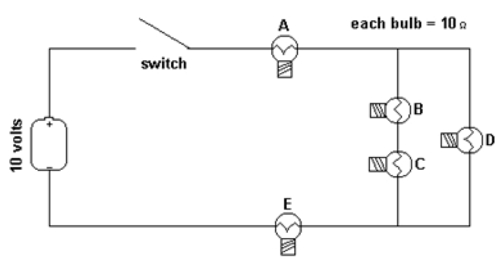


50. If all of the resistors in the simple circuit to the left have the same resistance, which would dissipate the greatest power?
(A) resistor A
(B) resistor B
(C) resistor C
(D) resistor D

51. Each member of a family of six owns a computer rated at 500 watts in a 120 V circuit. If all computers are plugged into a single circuit protected by a 20 ampere fuse, what is the maximum number of the computers can be operating at the same time?
(A) 2 (B) 3 (C) 4 (D) 5 or more

Questions 52-53

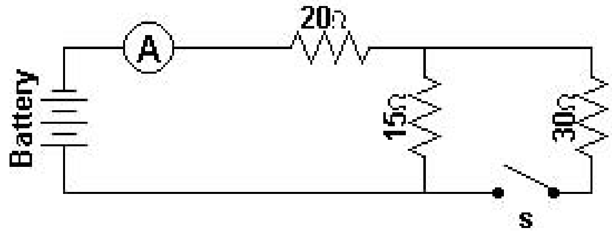
Five identical light bulbs, each with a resistance of 10 ohms, are connected in a simple electrical circuit with a switch and a 10 volt battery as shown in the diagram below.



52. The steady current in the above circuit would be closest to which of the following values?
(A) 0.2 amp (B) 0.37 amp (C) 0.5 amp (D) 2.0 amp

53. Which bulb (or bulbs) could burn out without causing other bulbs in the circuit to also go out?
(A) only bulb D (B) only bulbs C or D
(C) only bulb E (D) only bulbs A or E

Questions 54-56



An ideal battery, an ideal ammeter, a switch and three resistors are connected as shown. With the switch open as shown in the diagram the ammeter reads 2.0 amperes.

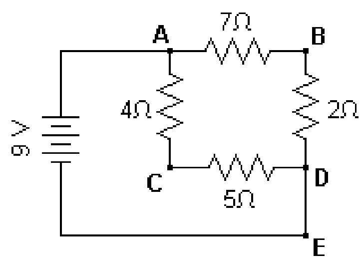
54. With the switch open, what would be the potential difference across the 15 ohm resistor?
(A) 30 V (B) 60 V (C) 70 V (D) 110V

55. With the switch open, what must be the voltage supplied by the battery?
(A) 30 V (B) 60 V (C) 70 V (D) 110 V

56. When the switch is closed, what would be the current in the circuit?
(A) 1.1 A (B) 2.0 A (C) 2.3 A (D) 3.0 A

57. How much current flows through a 4 ohm resistor that is dissipating 36 watts of power?
(A) 2.25 amps (B) 3.0 amps (C) 4.24 amps (D) 9.0 amps

Questions 58-59

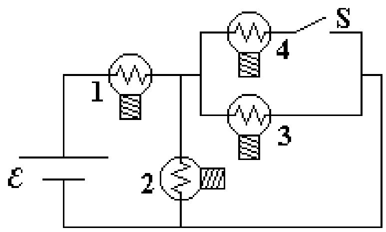


A 9–volt battery is connected to four resistors to form a simple circuit as shown above.

58. How would the current through the 2 ohm resistor compare to the current through the 4 ohm resistor?
(A) one–forth as large
(B) four times as large
(C) twice as large
(D) equally as large

59. What would be the potential at point B with respect to point C in the above circuit?
(A) +7 V (B) +3 V (C) –3 V (D) –7 V

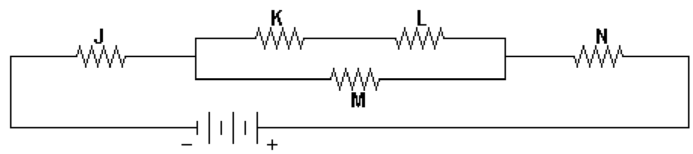
60. A cylindrical resistor has length *L* and radius *r*. This piece of material is then drawn so that it is a cylinder with new length 2*L*. What happens to the resistance of this material because of this process?
(A) the resistance is quartered.
(B) the resistance is halved.
(C) the resistance is doubled.
(D) the resistance is quadrupled.



61. A circuit is connected as shown. All light bulbs are identical. When the switch in the circuit is closed illuminating bulb #4, which other bulb(s) also become brighter?
(A) Bulb #1 only (B) Bulb #2 only (C) Bulbs #2 and #3 only (D) Bulbs #1, #2, and #3

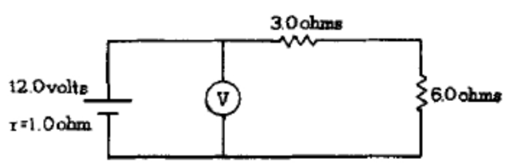
62. A cylindrical graphite resistor has length L and cross–sectional area A. It is to be placed into a circuit, but it first must be cut in half so that the new length is ½ L. What is the ratio of the new resistivity to the old resistivity of the cylindrical resistor?
(A) 4 (B) 2 (C) 1 (D) ½

<u>Questions 63-64</u>
The diagram below shows five identical resistors connected in a combination series and parallel circuit to a voltage source.

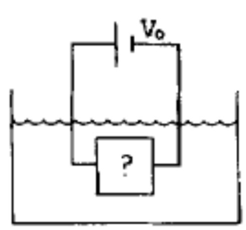


63. Through which resistor(s) would there be the greatest current?
(A) J only (B) M only (C) N only (D) J&N only

64. Which resistor(s) have the greatest rate of energy dissipation?
(A) J only (B) M only (C) N only (D) J&N only



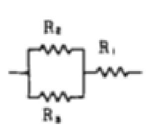
65. In the circuit above the voltmeter V draws negligible current and the internal resistance of the battery is 1.0 ohm. The reading of the voltmeter is
(A) 10.5 V (B) 10.8 V (C) 11.6 V (D) 12.0 V

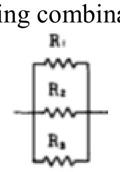


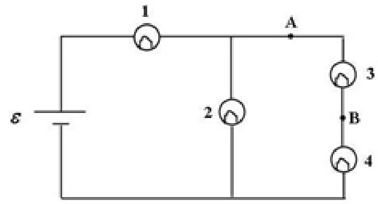
66. Suppose you are given a constant voltage source V_0 and three resistors R_1, R_2, and R_3 with $R_1 > R_2 > R_3$. If you wish to heat water in a pail which of the following combinations of resistors will give the most rapid heating?

(A) 

(B) 

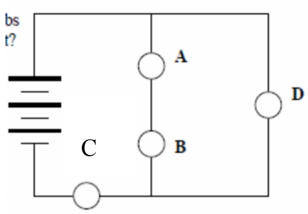
(C) 

(D) 

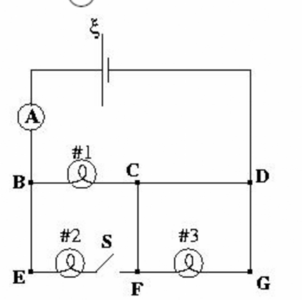


67. For the circuit shown, a shorting wire of negligible resistance is added to the circuit between points A and B. When this shorting wire is added, bulb #3 goes out. Which bulbs (all identical) in the circuit brighten?
(A) Only Bulb 2 (B) Only Bulb 4 (C) Only Bulbs 1 and 4 (D) Bulbs 1, 2 and 4

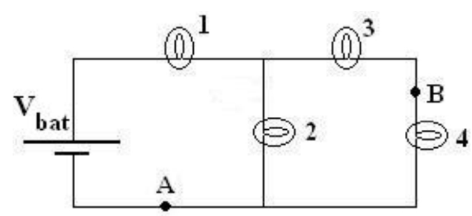
68. A student wants to make a brighter light bulb. He decides to modify the filament. How should the filament of a light bulb be modified in order to make the light bulb produce more light at a given voltage?
(A) Increase the resistivity only.
(B) Increase the diameter only.
(C) Decrease the diameter only.
(D) the length only.



69. In the circuit diagram to the left, all of the bulbs are identical. Which bulb will be the brightest?
(A) A (B) B (C) C (D) D

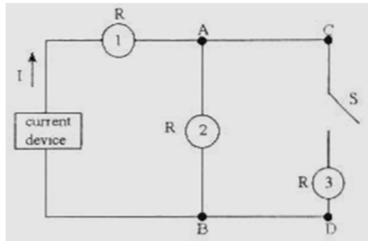


70. For the circuit shown, the ammeter reading is initially *I.* The switch in the circuit then is closed. Consequently:
(A) The ammeter reading decreases.
(B) The potential difference between *E* and *F* increases.
(C) The potential difference between *E* and *F* stays the same.
(D) Bulb #3 lights up more brightly.

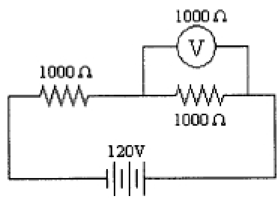


71. For the circuit shown, when a shorting wire (no resistance) connects the points labeled A and B, which of the numbered light bulbs become brighter? Assume that all four bulbs are identical and have resistance R .
(A) Bulb 2 only (B) Bulb 3 only (C) Bulbs 1 and 3 only (D) Bulbs 1, 2, and 3

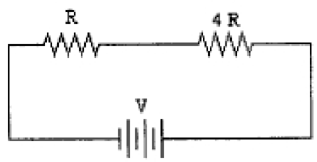
72. Consider a simple circuit containing a battery and three light bulbs. Bulb *A* is wired in parallel with bulb *B* and this combination is wired in series with bulb *C*. What would happen to the brightness of the other two bulbs if bulb *A* were to burn out?
(A) Both would get brighter.
(B) Bulb *B* would get brighter and bulb *C* would get dimmer.
(C) Bulb *B* would get dimmer and bulb *C* would get brighter.
(D) Only bulb *B* would get brighter



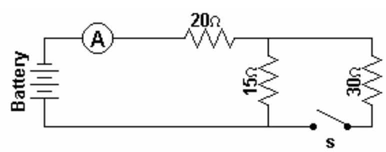
73. In the circuit shown above, a constant current device is connected to some identical light bulbs. After the switch S in the circuit is closed, which statement is correct about the circuit?
(A) Bulb #2 becomes brighter. (B) Bulb #1 becomes dimmer.
(C) All three bulbs become equally brighter. (D) The voltage between points C and D is decreased.



74. Two 1000 Ω resistors are connected in series to a 120–volt electrical source. A voltmeter with a resistance of 1000 Ω is connected across the last resistor as shown. What would be the reading on the voltmeter?
(A) 80 V (B) 60 V (C) 40 V (D) 30 V



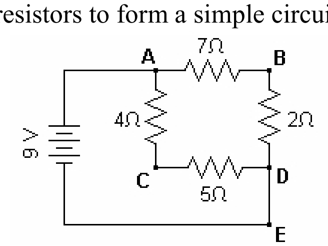
75. Two resistors, one with resistance R and the second with resistance $4R$ are placed in a circuit with a voltage V. If resistance R dissipates power P, what would be the power dissipated by the $4R$ resistance?
(A) 4 P (B) 2 P (C) 1/2 P (D) 1/4 P



76. A battery, an ammeter, three resistors, and a switch are connected to form the simple circuit shown above. When the switch is closed what would happen to the potential difference across the 15 ohm resistor?
(A) it would equal the potential difference across the 20 ohm resistor
(B) it would be twice the potential difference across the 30 ohm resistor
(C) it would equal the potential difference across the 30 ohm resistor
(D) it would be half the potential difference across the 30 ohm resistor

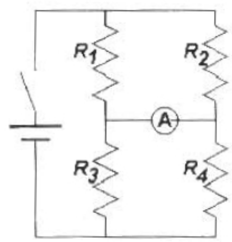
Questions 77-78

A 9–volt battery is connected to four resistors to form a simple circuit as shown below.



77. What would be the current at point E in the circuit?
(A) 2 amp (B) 4 amp (C) 5 amp (D) 7 amp

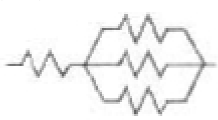
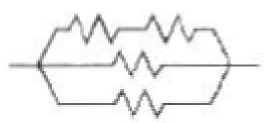
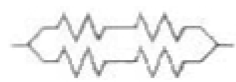
78. What would be the potential at point B with respect to point D?
(A) +2 V (B) +4 V (C) +5 V (D) +7 V

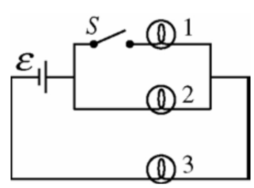


79. Four resistors, R_1, R_2, R_3, and R_4, are connected in the circuit diagram above. When the switch is closed, current flows in the circuit. If no current flows through the ammeter when it is connected as shown, what would be the value of R_3?

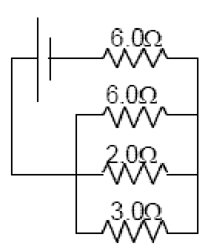
(A) $\frac{R_1+R_4}{(R_1+R_2)(R_3+R_4)}$ (B) $\frac{(R_1+R_2)(R_4)}{(R_2+R_4)}$ (C) $\frac{R_1+R_2}{R_4}$ (D) $R_1\frac{R_4}{R_2}$

80. Given 4 identical resistors of resistance R, which of the following circuits would have an equivalent resistance of 4/3 R?

(A) 
(B) 
(C) 
(D) 

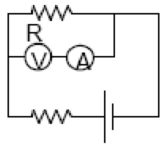


81. The three lightbulbs in the circuit above are identical, and the battery has zero internal resistance. When switch S is closed to cause bulb 1 to light, which of the other two bulbs increase(s) in brightness?
(A) Neither bulb
(B) Bulb 2 only
(C) Bulb 3 only
(D) Both bulbs

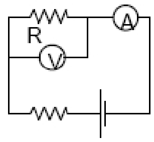


82. In the electric circuit shown above, the current through the 2.0 Ω resistor is 3.0 A. Approximately what is the emf of the battery?
(A) 51 V (B) 42 V (C) 36 V (D) 24 V

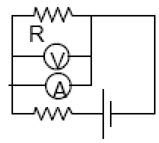
83. Which of the following wiring diagrams could be used to experimentally determine R using Ohm's Law? Assume an ideal voltmeter and an ideal ammeter.



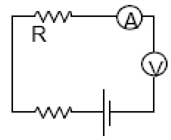
(A)



(B)

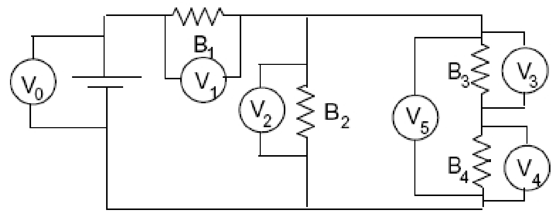


(C)



(D)

Questions 84-85

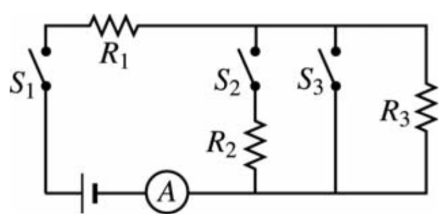


B_1, B_2, B_3, and B_4 are identical light bulbs. There are six voltmeters connected to the circuit as shown. All voltmeters are connected so that they display positive voltages. Assume that the voltmeters do not affect the circuit.

84. If B_2 were to burn out, opening the circuit, which voltmeter(s) would read zero volts?
(A) none would read zero (B) only V_2 (C) only V_3 and V_4 (D) only V_2, V_4, and V_5

85. If B_2 were to burn out, opening the circuit, what would happen to the reading of V_1? Let V be its original reading when all bulbs are functioning and let $\underline{V}$ be its reading when B_2 is burnt out.
(A) $\underline{V} > 2V$ (B) $2V > \underline{V} > V$ (C) $V > \underline{V} > V/2$ (D) $V/2 > \underline{V}$

Questions 86-87



In the circuit above, the resistors all have the same resistance. The battery, wires, and ammeter have negligible resistance. A closed switch also has negligible resistance.

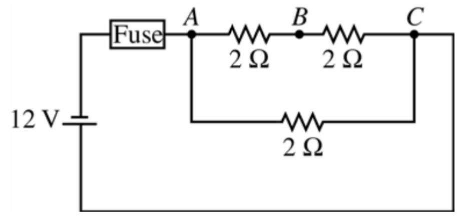
86. Closing which of the switches will produce the greatest power dissipation in R_2?
(A) S_1 only (B) S_2 only (C) S_1 and S_2 only (D) S_1 and S_3 only

87. Closing which of the switches will produce the greatest reading on the ammeter?
(A) S_2 only (B) S_3 only (C) S_1 and S_2 (D) S_1 and S_3

88. Closing which of the switches will produce the greatest voltage across R_3?
(A) S_1 only (B) S_2 only (C) S_1 and S_2 only (D) S_1 and S_3 only

89. Two cables can be used to wire a circuit. Cable A has a lower resistivity, a larger diameter, and a different length than cable B. Which cable should be used to minimize heat loss if the same current is maintained in either cable?
(A) Cable A
(B) Cable B
(C) The heat loss is the same for both.
(D) It cannot be determined without knowing the length of each cable.

Questions 90-91



An electric circuit consists of a 12 V battery, an ideal 10 A fuse, and three 2 Ω resistors connected as shown above.

90. What would be the reading on a voltmeter connected across points A and C ?
(A) 12 V (B) 6 V (C) 3 V (D) 2 V

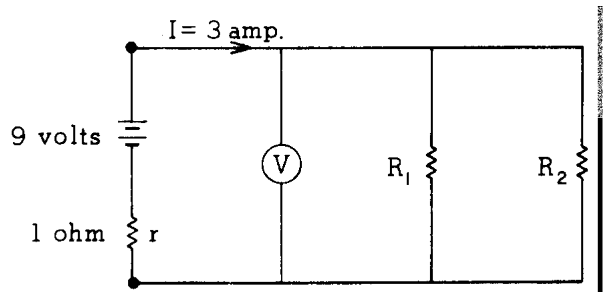
91. What would be the reading on an ammeter inserted at point B ?
(A) 9 A (B) 6 A (C) 3 A (D) 2 A

92. A length of wire of resistance R is connected across a battery with zero internal resistance. The wire is then cut in half and the two halves are connected in parallel. When the combination is reconnected across the battery, what happens to the resultant power dissipated and the current drawn from the battery?

	Power	**Current**
(A)	Doubles	Doubles
(B)	Quadruples	Doubles
(C)	Doubles	Quadruples
(D)	Quadruples	Quadruples

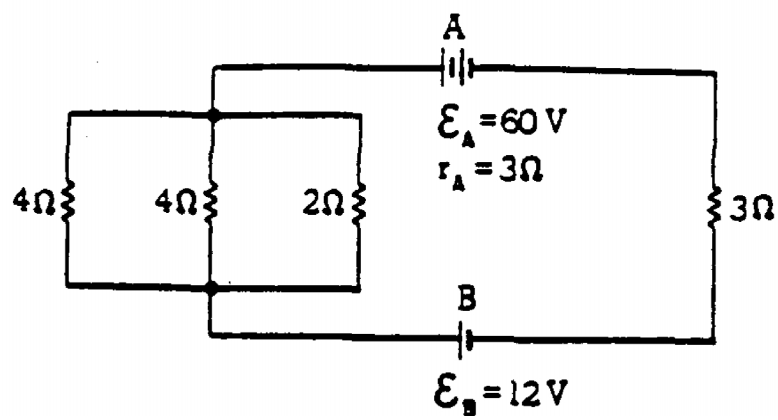
93. A fixed voltage is applied across the length of a tungsten wire. An increase in the power dissipated by the wire would result if which of the following could be increased?
(A) The resistivity of the tungsten
(B) The cross-sectional area of the wire
(C) The length of the wire
(D) The temperature of the wire

AP Physics Free Response Practice – Circuits
WARNING ONLY CIRCUITS WITH RESISTORS ARE ON AP PHYSICS 1



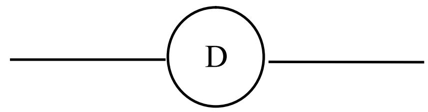
1976B3. In the circuit shown above, the current delivered by the 9-volt battery of internal resistance 1 ohm is 3 amperes. The power dissipated in R_2 is 12 watts.

a. Determine the reading of voltmeter V in the diagram.
b. Determine the resistance of R_2.
c. Determine the resistance of R_1.



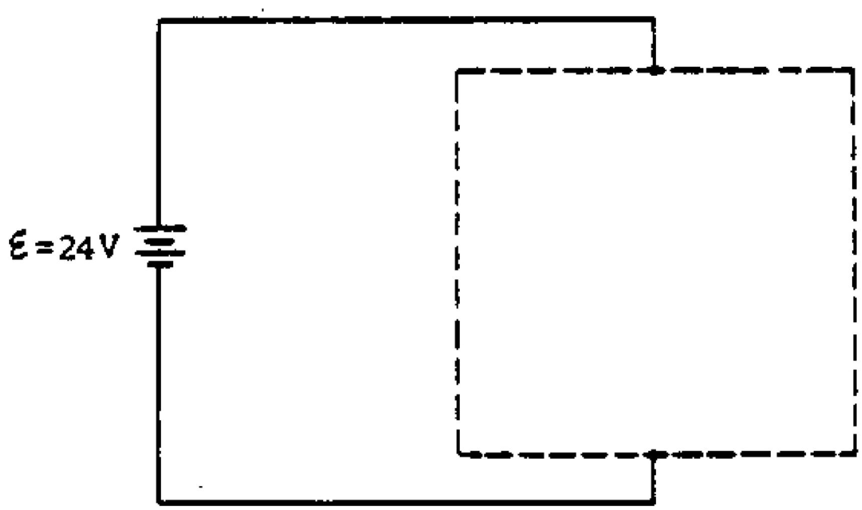
1981B4. A circuit consists of battery A of emf $\mathcal{E}_A$ = 60 volts and internal resistance r_A = 3 ohms; battery B of emf $\mathcal{E}_B$ = 12 volts and internal resistance r_B = 1 ohm; and four resistors connected as shown in the diagram above.

a. Calculate the current in the 2-ohm resistor.
b. Calculate the power dissipated in the 3-ohm resistor.
c. Calculate the terminal voltage of battery B.

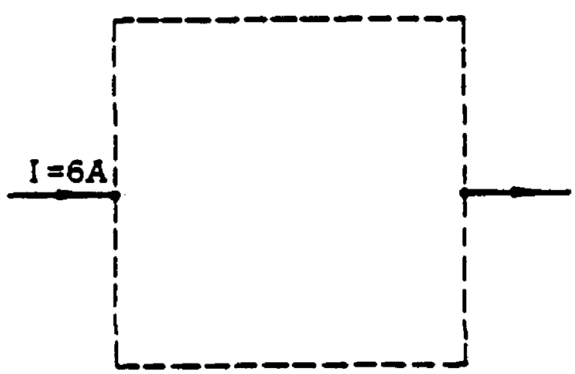


1980B2. The electrical device whose symbol is shown above requires a terminal voltage of 12 volts and a current of 2 amperes for proper operation.

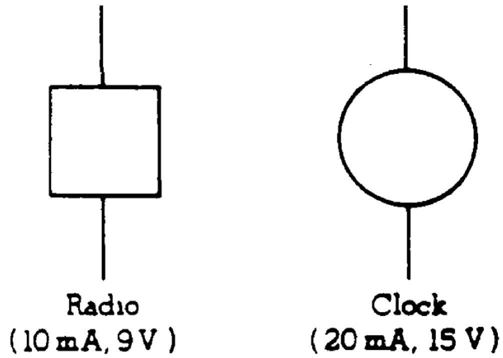
a. Using only this device and one or more 3-ohm resistors design a circuit so that the device will operate properly when the circuit is connected across a battery of emf 24 volts and negligible internal resistance. Within the dashed-line box in the diagram below, draw the circuit using the symbol for the device and the appropriate symbol for each 3-ohm resistor.



b. Using only this device and one or more 3-ohm resistors, design a circuit so that the device will operate properly when connected to a source that supplies a fixed current of 6 amperes. Within the dashed-line box in the diagram below, draw the circuit using the symbol for the device and the appropriate symbol.

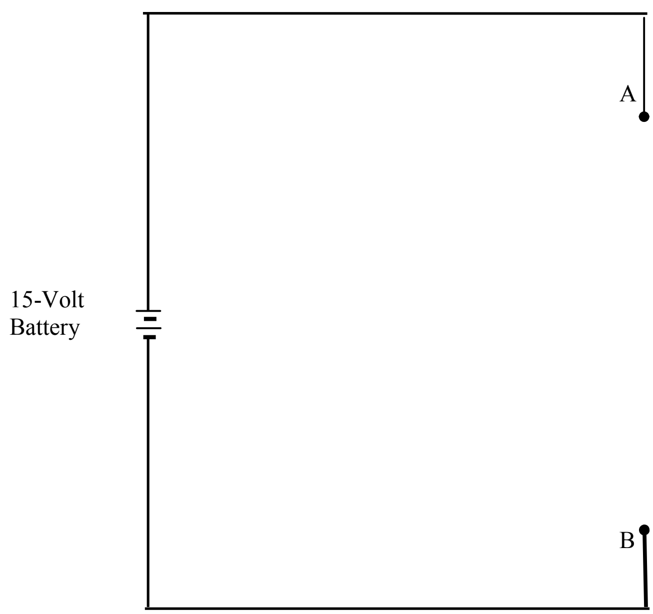


c. Calculate the power dissipation In each 3-ohm resistor used in the circuit in part b..



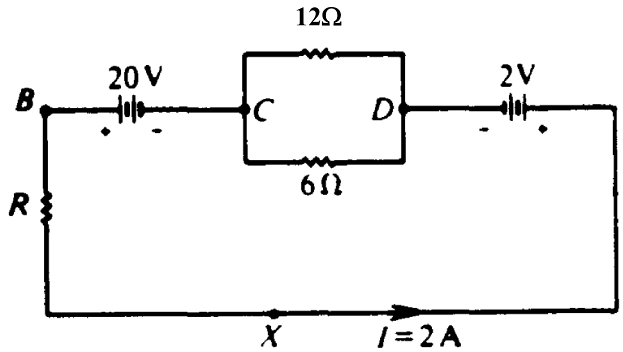
1982B4. A cabin contains only two small electrical appliances: a radio that requires 10 milliamperes of current at 9 volts, and a clock that requires 20 milliamperes at 15 volts. A 15-volt battery with negligible internal resistance supplies the electrical energy to operate the radio and the clock.

a. Complete the diagram below to show how the radio, the clock, and a single resistor R can be connected between points A and B so that the correct potential difference is applied across each appliance. Use the symbols in the diagram above to indicate the radio and the clock.



b. Calculate the resistance of R.

c. Calculate the electrical energy that must be supplied by the battery to operate the circuits for 1 minute.



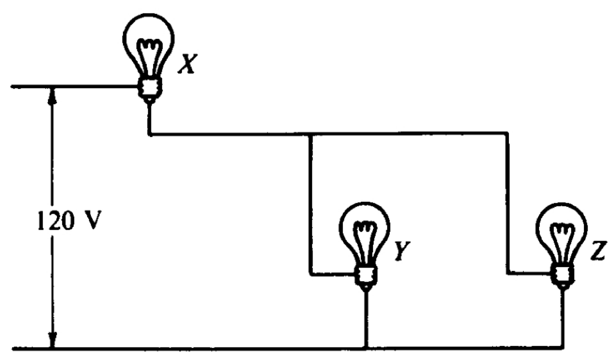
1983B3. The circuit shown above is constructed with two batteries and three resistors. The connecting wires may be considered to have negligible resistance. The current I is 2 amperes.

a. Calculate the resistance R.

b. Calculate the current in the
   i. 6-ohm resistor
   ii. 12-ohm resistor

c. The potential at point X is 0 volts. Calculate the electric potential at points B. C, and D in the circuit.

d. Calculate the power supplied by the 20-volt battery.



1986B3. In the circuit shown above, X, Y. and Z represent three light bulbs, each rated at 60 watts, 120 volts. Assume that the resistances of the bulbs are constant and do not depend on the current.

a. What is the resistance of each bulb?

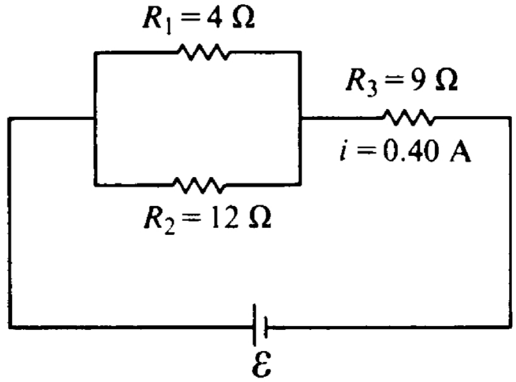
b. What is the equivalent resistance of the three light bulbs when arranged as shown?

c. What is the total power dissipation of this combination when connected to a 120-volt source as shown?

d. What is the current in bulb X?

e. What is the potential difference across bulb X?

f. What is the potential difference across bulb Zd ?

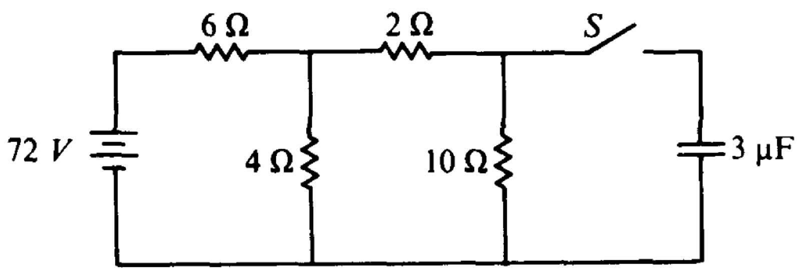


1987B4. Three resistors are arranged in a circuit as shown above. The battery has an unknown but constant emf $\mathcal{E}$ and a negligible internal resistance.

a. Determine the equivalent resistance of the three resistors.

The current I in resistor R_3 is 0.40 ampere.

b. Determine the emf $\mathcal{E}$ (Voltage) of the battery.
c. Determine the potential difference across resistor R_1
d. Determine the power dissipated in resistor R_1
e. Determine the amount of charge that passes through resistor R_3 in one minute.



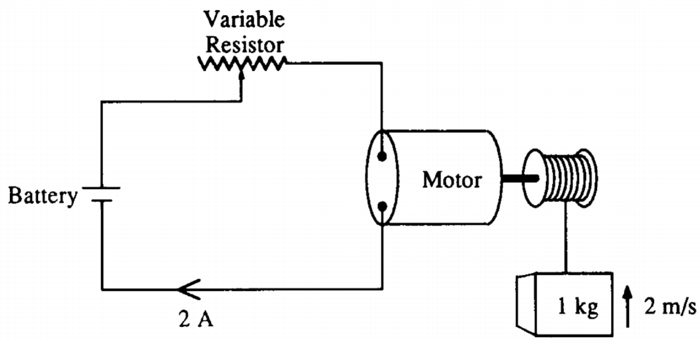
1988B3. The circuit shown above includes a switch S, which can be closed to connect the 3-microfarad capacitor in parallel with the 10-ohm resistor or opened to disconnect the capacitor from the circuit.

Case 1: Switch S is open. The capacitor is not connected. Under these conditions determine:

a. the current in the battery
b. the current in the 10-ohm resistor
c. the potential difference across the 10-ohm resistor

Case II: Switch S is closed. The capacitor is connected. After some time, the currents reach constant values. Under these conditions determine:

d. the charge on the capacitor
e. the energy stored in the capacitor



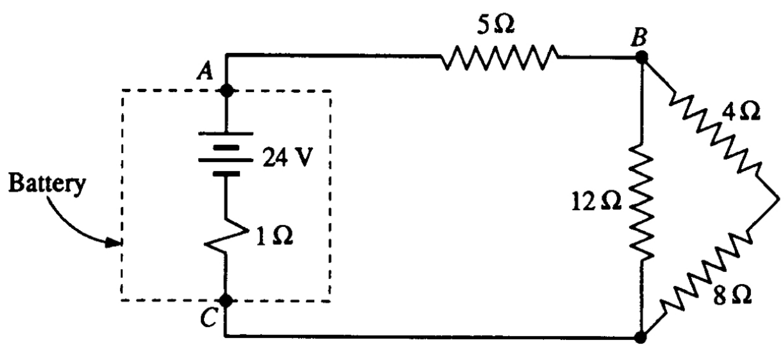
1989B3. A series circuit consists of a battery of negligible internal resistance, a variable resistor, and an electric motor of negligible resistance. The current in the circuit is 2 amperes when the resistance in the circuit is adjusted to 10 ohms. Under these conditions the motor lifts a 1-kilogram mass vertically at a constant speed of 2 meters per second.

a. Determine the electrical power that is
   i. dissipated in the resistor
   ii. used by the motor in lifting the mass
   iii. supplied by the battery

b. Determine the potential difference across
   i. the resistor
   ii. the motor
   iii. the battery

The resistor is now adjusted until the mass rises vertically at a constant speed of 3 meters per second. The voltage drop across the motor is proportional to the speed of the motor, and the current remains constant.

c. Determine the voltage drop across the motor.
d. Determine the new resistance in the circuit.



1990B3. A battery with an emf of 24 volts and an internal resistance of 1 ohm is connected to an external circuit as shown above. Determine each of the following:

a. the equivalent resistance of the combination of the 4-ohm, 8-ohm, and 12-ohm resistors
b. the current in the 5-ohm resistor
c. the terminal voltage, V_{AC} of the battery
d. the rate at which energy is dissipated in the 12-ohm resistor
e. the magnitude of the potential difference V_{BC}
f. the power delivered by the battery to the external circuit

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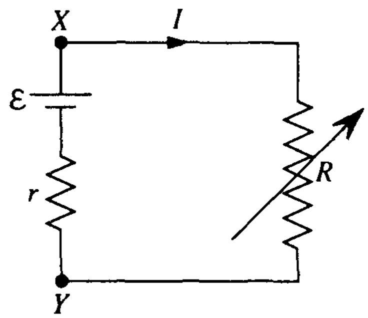
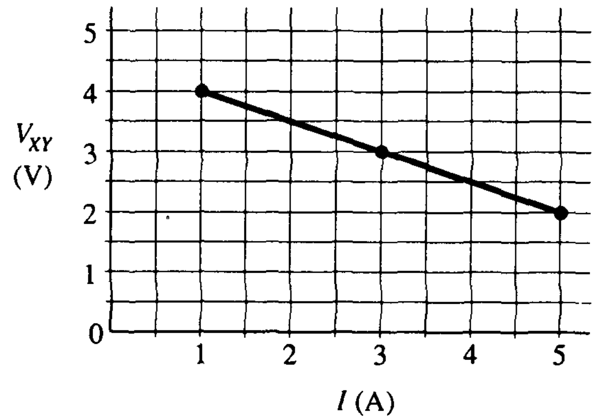




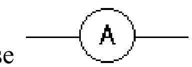
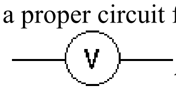
1991B4. A battery with emf $\mathcal{E}$ and internal resistance r is connected to a variable resistance R at points X and Y. as shown above on the left. Varying R changes both the current I and the terminal voltage V_{XY}. The quantities I and V_{XY} are measured for several values of R and the data are plotted in a graph, as shown above on the right.

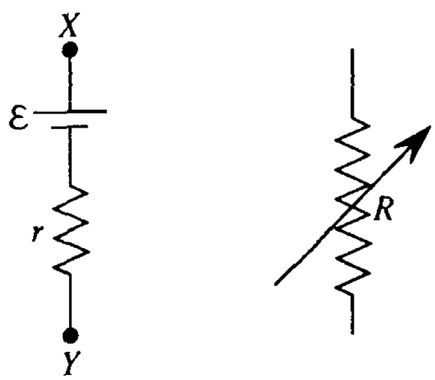
a. Determine the emf $\mathcal{E}$ of the battery.

b. Determine the internal resistance r of the battery.

c. Determine the value of the resistance R that will produce a current I of 3 amperes.

d. Determine the maximum current that the battery can produce.

e. The current and voltage measurements were made with an ammeter and a voltmeter. On the diagram below, show a proper circuit for performing these measurements. Use  to represent the ammeter and  to represent the voltmeter.



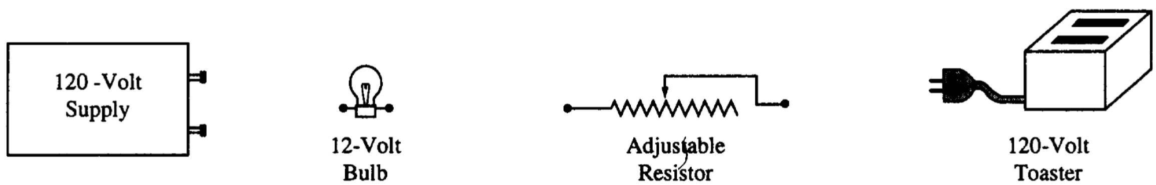
1995B2. A certain light bulb is designed to dissipate 6 watts when it is connected to a 12-volt source.

a. Calculate the resistance of the light bulb.

b. If the light bulb functions as designed and is lit continuously for 30 days, how much energy is used? Be sure to indicate the units in your answer.

The 6-watt, 12-volt bulb is connected in a circuit with a 1,500-watt, 120-volt toaster; an adjustable resistor; and a 120-volt power supply. The circuit is designed such that the bulb and the toaster operate at the given values and, if the light bulb fails, the toaster will still function at these values.

c. On the diagram below, draw in wires connecting the components shown to make a complete circuit that will function as described above.



d. Determine the value of the adjustable resistor that must be used in order for the circuit to work as designed.

e. If the resistance of the adjustable resistor is increased, what will happen to the following?

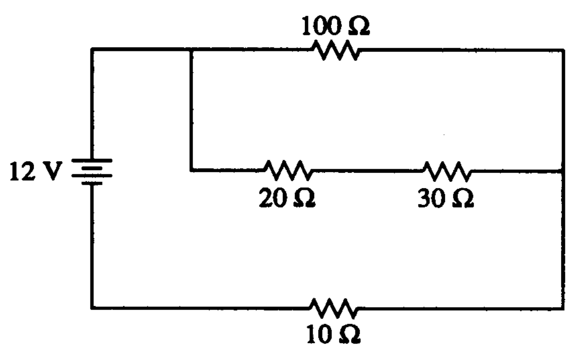
  i. The brightness of the bulb. Briefly explain your reasoning.

  ii. The power dissipated by the toaster. Briefly explain your reasoning.

1996B4. A student is provided with a 12.0-V battery of negligible internal resistance and four resistors with the following resistances: 100 Ω, 30 Ω, 20 Ω, and 10 Ω. The student also has plenty of wire of negligible resistance available to make connections as desired.

a. Using all of these components, draw a circuit diagram in which each resistor has nonzero current flowing through it, but in which the current from the battery is as small as possible.

b. Using all of these components, draw a circuit diagram in which each resistor has nonzero current flowing through it, but in which the current from the battery is as large as possible (without short circuiting the battery).



The battery and resistors are now connected in the circuit shown above.

c. Determine the following for this circuit.

  i. The current in the 10-Ω resistor

  ii. The total power consumption of the circuit

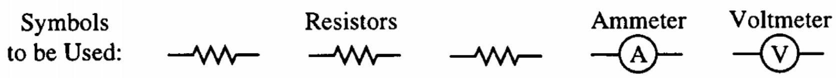
d. Assuming that the current remains constant, how long will it take to provide a total of 10 kJ of electrical energy to the circuit?

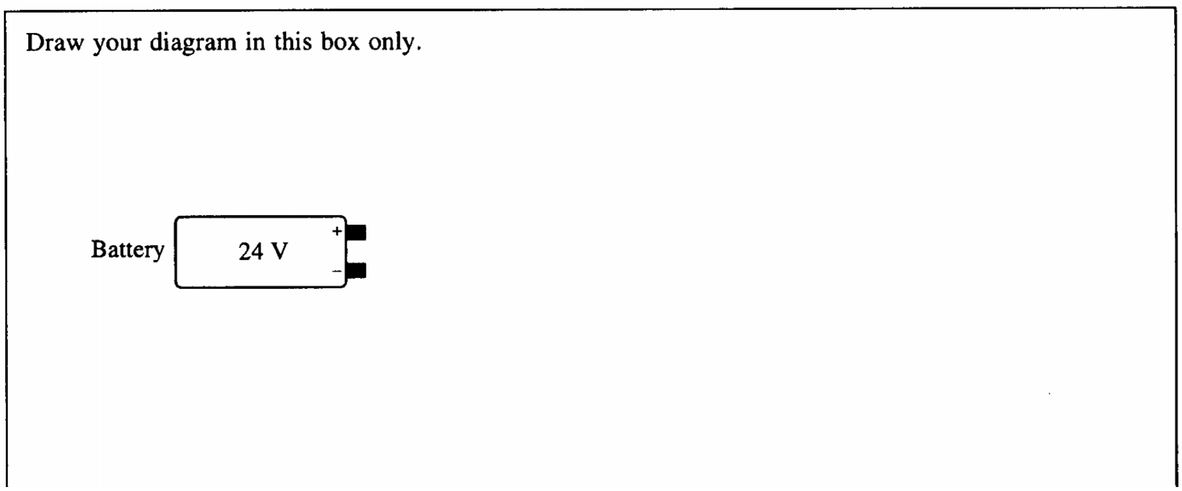
1997B4 (modified) Three identical resistors, each of resistance 30 Ω are connected in a circuit to heat water in a glass beaker. 24 V battery with negligible internal resistance provides the power. The three resistors may be connected in series or in parallel.

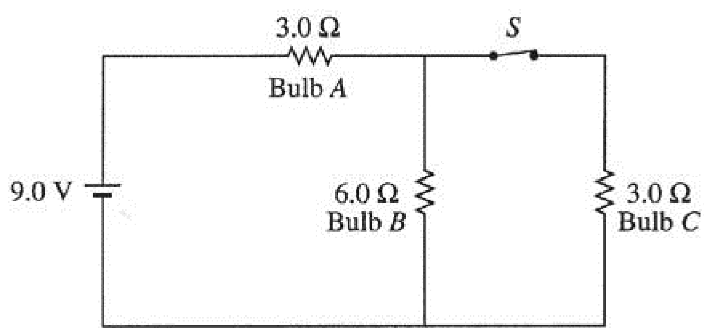
a. i. If they are connected in series, what power is developed in the circuit?

ii. If they are connected in parallel, what power is developed in the circuit?

b. Using the battery and one or more of the resistors, design a circuit that will heat the water at the fastest rat when the resistor(s) are placed in the water. Include an ammeter to measure the current in the circuit and a voltmeter to measure the total potential difference of the circuit. Assume the wires are insulated and have no resistance. Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram.







2002B3B. Lightbulbs of fixed resistance 3.0 Ω and 6.0 Ω, a 9.0 V battery, and a switch S are connected as shown in the schematic diagram above. The switch S is closed.

a. Calculate the current in bulb A.

b. Which lightbulb is brightest? Justify your answer.

c. Switch S is then opened. By checking the appropriate spaces below, indicate whether the brightness of each lightbulb increases, decreases, or remains the same. Explain your reasoning for each lightbulb.

i. Bulb A: The brightness ____ increases ____decreases ____ remains the same

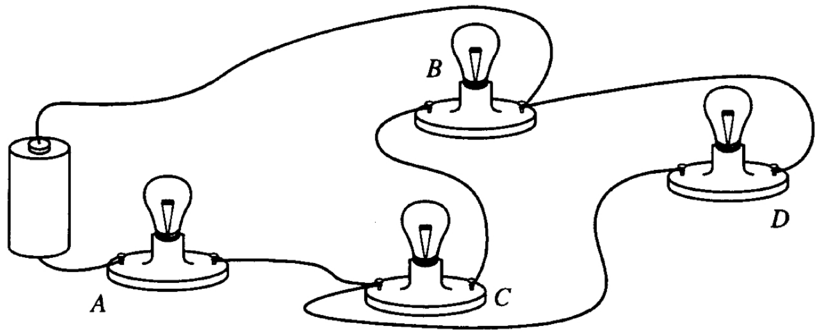
Explanation:

ii. Bulb B: The brightness ____increases ____decreases ____remains the same

Explanation:

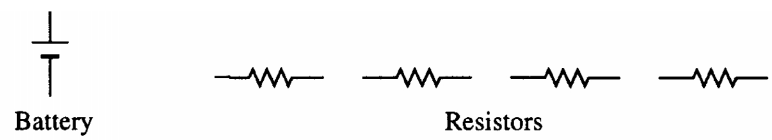
iii. Bulb C: The brightness ____increases ____decreases ____ remains the same

Explanation:



1998B4 In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

a. Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B. C, and D to refer to the corresponding lightbulbs.



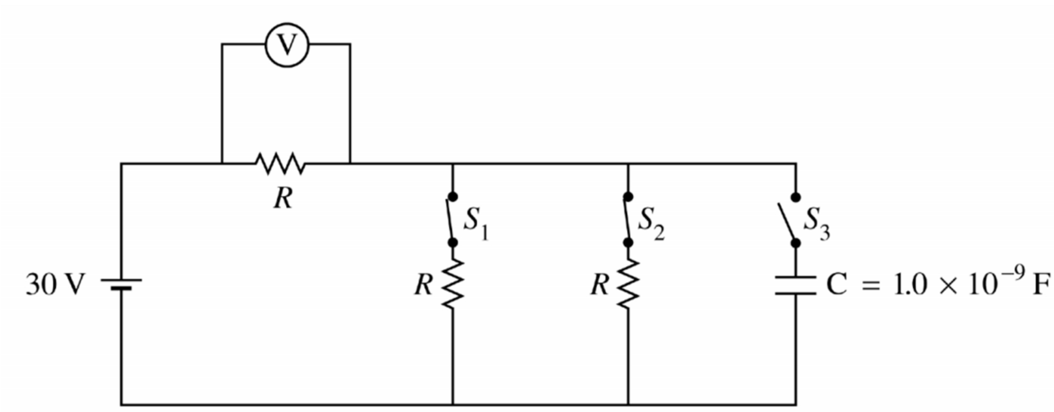
Draw your diagram in this box only.

b. List the bulbs in order of their brightnesses, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. Justify your answer.

c. Bulb D is then removed from its socket.

i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.

ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.



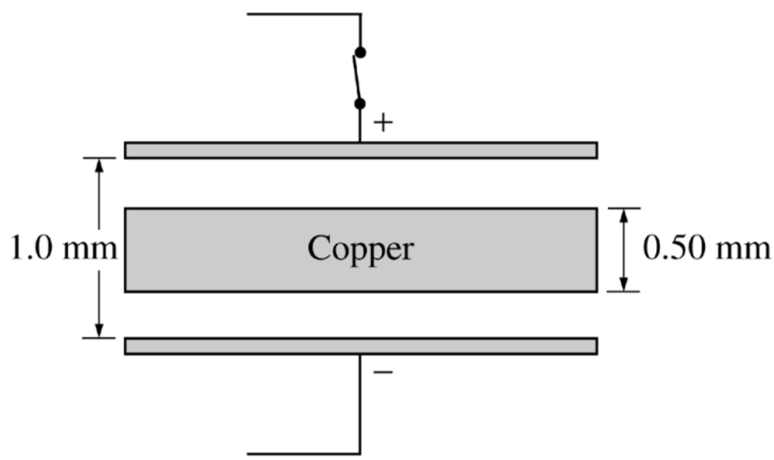
2000B3. Three identical resistors, each with resistance R, and a capacitor of 1.0×10^{-9} F are connected to a 30 V battery with negligible internal resistance, as shown in the circuit diagram above. Switches S_1 and S_2 are initially closed, and switch S_3 is initially open. A voltmeter is connected as shown.

a. Determine the reading on the voltmeter.

Switches S_1 and S_2 are now opened, and then switch S_3 is closed.

b. Determine the charge Q on the capacitor after S_3 has been closed for a very long time.

After the capacitor is fully charged, switches S_1 and S_2 remain open, switch S_3 remains closed, the plates are held fixed, and a conducting copper block is inserted midway between the plates, as shown below. The plates of the capacitor are separated by a distance of 1.0 mm, and the copper block has a thickness of 0.5 mm.



c. i. What is the potential difference between the plates?
ii. What is the electric field inside the copper block?
iii. On the diagram above, draw arrows to clearly indicate the direction of the electric field between the plates.
iv. Determine the magnitude of the electric field in each of the spaces between the plates and the copper block.

2002B3 Two lightbulbs, one rated 30 W at 120 V and another rated 40 W at 120 V, are arranged in two different circuits.

a. The two bulbs are first connected in parallel to a 120 V source.
   i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.
   ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

b. The bulbs are now connected in series with each other and a 120 V source.
   i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.
   ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

c. In the spaces below, number the bulbs in each situation described, in order of their brightness. (1= brightest, 4 = dimmest)

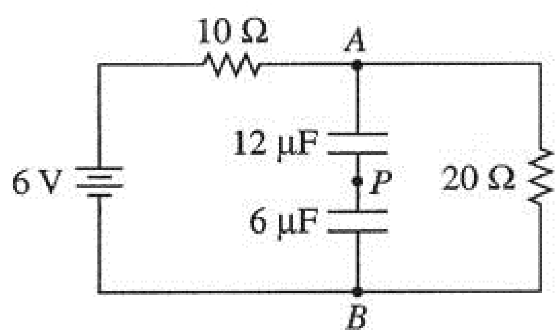
____30 W bulb in the parallel circuit

____40 W bulb in the parallel circuit

____30 W bulb in the series circuit

____40 W bulb in the series circuit

d. Calculate the total power dissipated by the two bulbs in each of the following cases.
   i. The parallel circuit
   ii. The series circuit



2003B2 A circuit contains two resistors (10 Ω and 20 Ω) and two capacitors (12 μF and 6 μF) connected to a 6 V battery, as shown in the diagram above. The circuit has been connected for a long time.

a. Calculate the total capacitance of the circuit.
b. Calculate the current in the 10 Ω resistor.
c. Calculate the potential difference between points A and B.
d. Calculate the charge stored on one plate of the 6 μF capacitor.
e. The wire is cut at point P. Will the potential difference between points A and B increase, decrease, or remain the same?

_____increase _____decrease _____remain the same

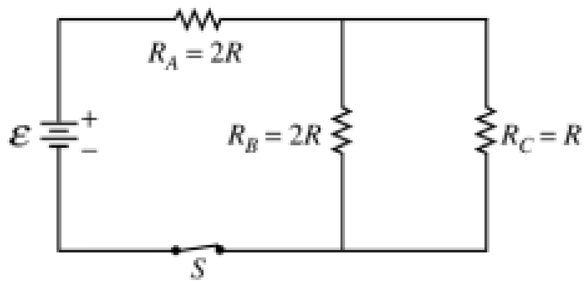
Justify your answer.

2003Bb2. A student is asked to design a circuit to supply an electric motor with 1.0 mA of current at 3.0 V potential difference.

a. Determine the power to be supplied to the motor.
b. Determine the electrical energy to be supplied to the motor in 60 s.
c. Operating as designed above, the motor can lift a 0.012 kg mass a distance of 1.0 m in 60 s at constant velocity. Determine the efficiency of the motor.

To operate the motor, the student has available only a 9.0 V battery to use as the power source and the following five resistors.

d. In the space below, complete a schematic diagram of a circuit that shows how one or more of these resistors can be connected to the battery and motor so that 1.0 mA of current and 3.0 V of potential difference are supplied to the motor. Be sure to label each resistor in the circuit with the correct value of its resistance.



2007B3. The circuit above contains a battery with negligible internal resistance, a closed switch S, and three resistors, each with a resistance of R or 2R.

a. i. Rank the currents in the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same current, give them the same ranking.

_______I_A _______I_B _______I_C

ii. Justify your answers.

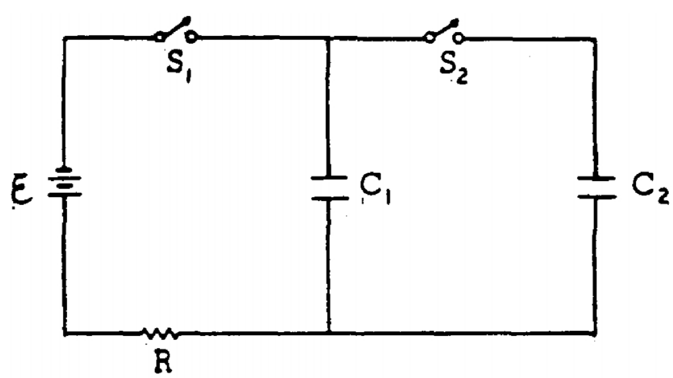
b. i. Rank the voltages across the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same voltage across them, give them the same ranking.

_______V_A _______V_B _______V_C

ii. Justify your answers.

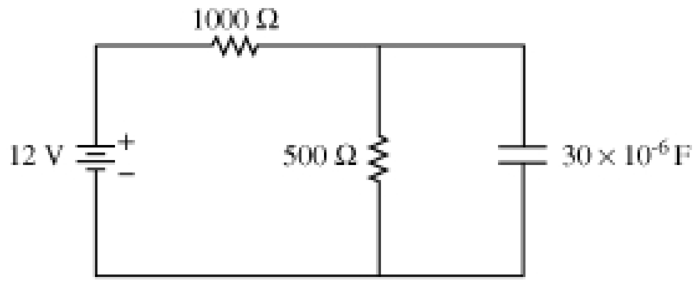
For parts c. through e., use $\mathcal{E}$ = 12 V and R = 200 Ω.

c. Calculate the equivalent resistance of the circuit.
d. Calculate the current in resistor R_C.
e. The switch S is opened, resistor R_B is removed and replaced by a capacitor of capacitance 2.0×10^{-6} F, and the switch S is again closed. Calculate the charge on the capacitor after all the currents have reached their final steady-state values.



1975E2. In the diagram above, V = 100 volts; C_1 = 12 microfarads; C_2 = 24 microfarads; R = 10 ohms. Initially, C_1 and C_2 are uncharged, and all switches are open.

a. First, switch S_1 is closed. Determine the charge on C_1 when equilibrium is reached.
b. Next S_1 is opened and afterward S_2 is closed. Determine the charge on C_1 when equilibrium is again reached.
c. For the equilibrium condition of part b., determine the voltage across C_1.
d. S_2 remains closed, and now S_1 is also closed. How much <u>additional</u> charge flows from the battery?



B2007b3. In the circuit above, a 12.0 V battery is connected to two resistors, one of resistance 1000 Ω and the other of resistance 500 Ω . A capacitor with a capacitance of 30×10^{-6} F is connected in parallel with the 500 Ω resistor. The circuit has been connected for a long time, and all currents have reached their steady states.

a. Calculate the current in the 500 Ω resistor.

b. i. Draw an ammeter in the circuit above in a location such that it could measure the current in the 500 Ω resistor. Use the symbol Ⓐ to indicate the ammeter.

ii. Draw a voltmeter in the circuit above in a location such that it could measure the voltage across the 1000 Ω, resistor. Use the symbol Ⓥ to indicate the voltmeter.

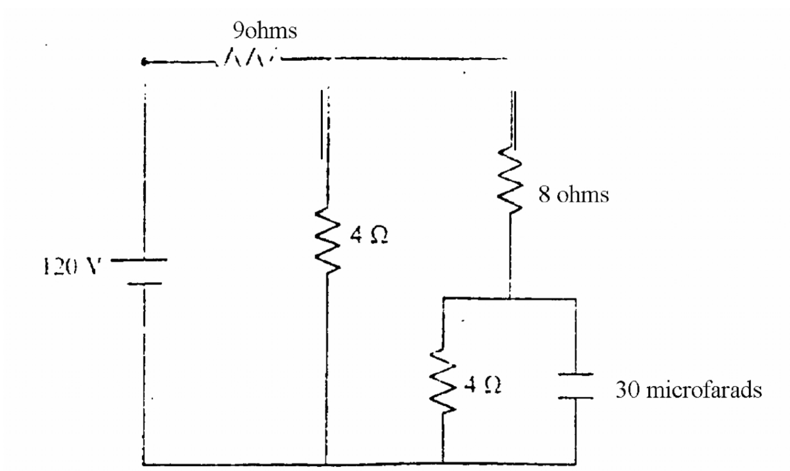
c. Calculate the charge stored on the capacitor.

d. Calculate the power dissipated in the 1000 Ω resistor.

e. The capacitor is now discharged, and the 500 Ω resistor is removed and replaced by a resistor of greater resistance. The circuit is reconnected, and currents are again allowed to come to their steady-state values. Is the charge now stored on the capacitor larger, smaller, or the same as it was in part c.?

______Larger ______Smaller ______The same as

Justify your answer.



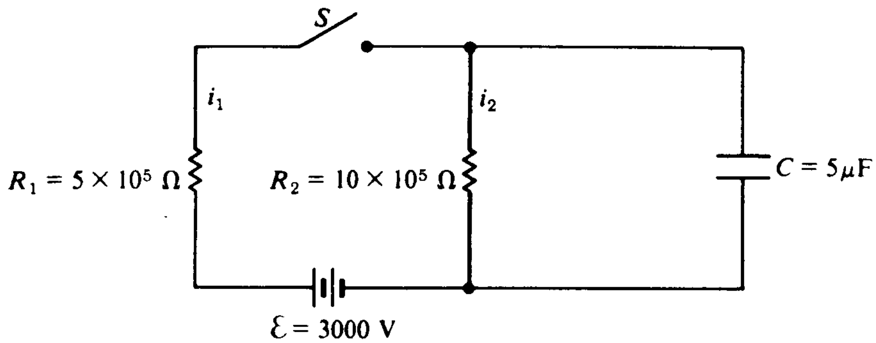
1988E2. In the circuit shown above. the battery has been connected for a long time so that the currents have steady values. Given these conditions, calculate each of the following

a. The current in the 9-ohm resistor.

b. The current in the 8-ohm resistor.

c. The potential difference across the 30-microfarad capacitor.

d. The energy stored in the 30-microfarad capacitor.

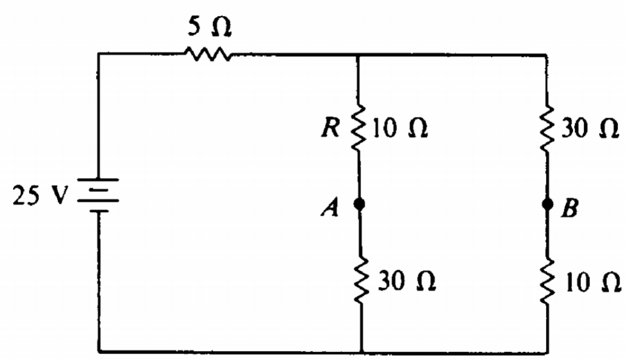


1985E2 (modified) In the circuit shown above, i_1 and i_2 are the currents through resistors R_1 and R_2, respectively. V_1, V_2, and V_c are the potential differences across resistor R_1 resistor R_2, and capacitor C, respectively. Initially the capacitor is uncharged.

a. Calculate the current i_1 immediately after switch S is closed.

Assume switch S has been closed for a long time.

b. Calculate the current i_2.
c. Calculate the charge Q on the capacitor.
d. Calculate the energy U stored in the capacitor.

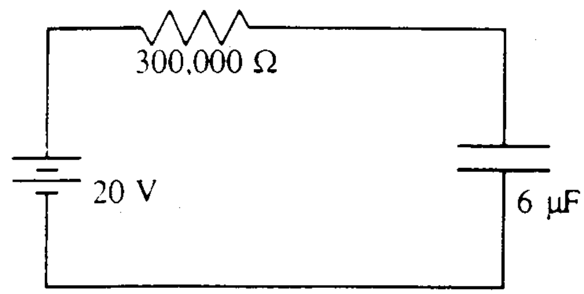


1986E2 (modified) Five resistors are connected as shown above to a 25-volt source of emf with zero internal resistance.

a. Determine the current in the resistor labeled R.

A 10-microfarad capacitor is connected between points A and B. The currents in the circuit and the charge on the capacitor soon reach constant values. Determine the constant value for each of the following.

b. The current in the resistor R
c. The charge on the capacitor



1989E3. A battery with an emf of 20 volts is connected in series with a resistor of 300,000 ohms and an air-filled parallel-plate capacitor of capacitance 6 microfarads.

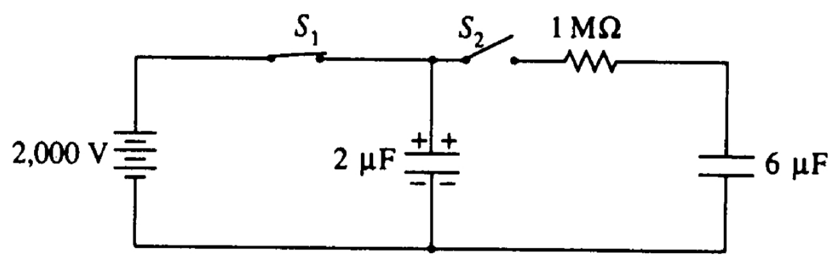
a. Determine the energy stored in the capacitor when it is fully charged.

The spacing between the capacitor plates is suddenly increased (in a time short enough so the charge does not have time to readjust) to four times its original value.

b. Determine the work that must be done in increasing the spacing in this fashion.
c. Determine the current in the resistor immediately after the spacing is increased.

After a long time. the circuit reaches a new static state.

d. Determine the total charge that has passed through the battery.
e. Determine the energy that has been added to the battery.



1992E2. The 2-microfarad (2×10^{-6} farad) capacitor shown in the circuit above is fully charged by closing switch S_1 and keeping switch S_2 open, thus connecting the capacitor to the 2,000-volt power supply.

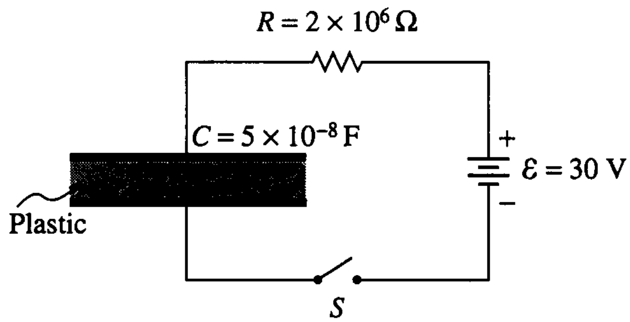
a. Determine each of the following for this fully charged capacitor.
   i. The magnitude of the charge on each plate of the capacitor.
   ii. The electrical energy stored in the capacitor.

At a later time, switch S_1 is opened. Switch S_2 is then closed, connecting the charged 2-microfarad capacitor to a l-megohm (1×10^6 Ω) resistor and a 6-microfarad capacitor, which is initially uncharged.

b. Determine the initial current in the resistor the instant after switch S_2 is closed.

Equilibrium is reached after a long period of time.

c. Determine the charge on the positive plate of <u>each</u> of the capacitors at equilibrium.
d. Determine the total electrical energy stored in the two capacitors at equilibrium. If the energy is greater than the energy determined in part a. ii., where did the increase come from? If the energy is less than the energy determined in part a. ii., where did the electrical energy go?



1995E2 (modified) A parallel-plate capacitor is made from two sheets of metal, each with an area of 1.0 square meter, separated by a sheet of plastic 1.0 millimeter (10^{-3} m) thick, as shown above. The capacitance is measured to be 0.05 microfarad (5×10^{-8} F).

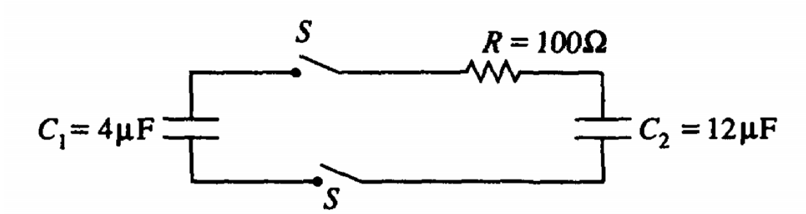
a. What is the dielectric constant of the plastic?

The uncharged capacitor is connected in series with a resistor R = 2×10^6 ohms, a 30-volt battery, and an open switch S, as shown above. The switch is then closed.

b. What is the initial charging current when the switch S is closed?
c. Determine the magnitude and sign of the final charge on the bottom plate of the fully charged capacitor.
d. How much electrical energy is stored in the fully charged capacitor?

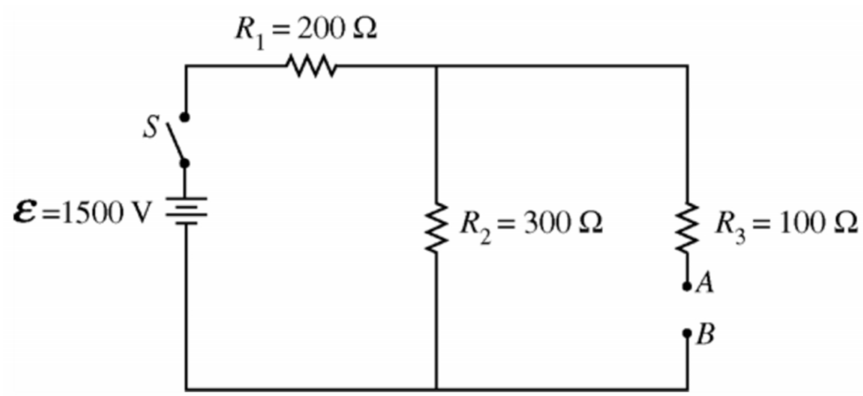
After the capacitor is fully charged, it is carefully disconnected, leaving the charged capacitor isolated in space. The plastic sheet is then removed from between the metal plates. The metal plates retain their original separation of 1.0 millimeter.

e. What is the new voltage across the plates?
f. If there is now more energy stored in the capacitor, where did it come from? If there is now less energy, what happened to it?



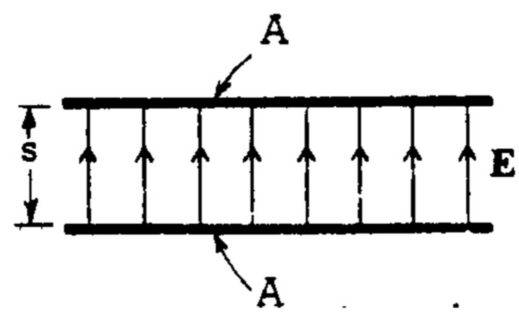
1996E2 (modified) Capacitors 1 and 2, of capacitance $C_1 = 4\mu F$ and $C_2 = 12\mu F$, respectively, are connected in a circuit as shown above with a resistor of resistance R = 100 Ω and two switches. Capacitor 1 is initially charged to a voltage $V_0 = 50$ V and capacitor 2 is initially uncharged. Both of the switches S are then closed at time t = 0.

a. What are the final charges on the positive plate of each of the capacitors 1 and 2 after equilibrium has been reached?
b. Determine the difference between the initial and the final stored energy of the system after equilibrium has been reached.



2008E2 (modified) In the circuit shown above, A and B are terminals to which different circuit components can be connected.

a. Calculate the potential difference across R_2 immediately after the switch S is closed in each of the following cases.
   i. A 50 Ω resistor connects A and B.
   ii. An initially uncharged 0.80 μF capacitor connects A and B.

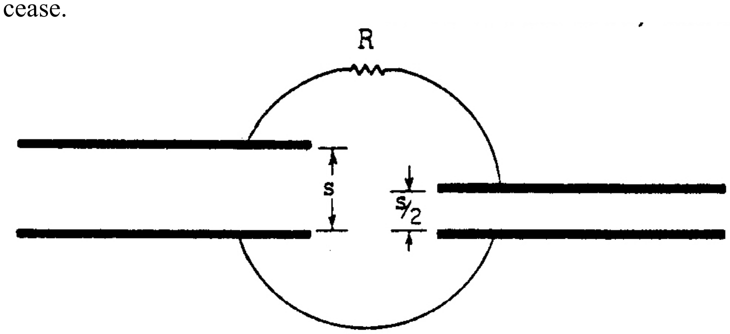


1978B3. A uniform electric field E is established between two capacitor plates, each of area A, which are separated by a distance s as shown above.

a. What is the electric potential difference V between the plates?
b. Specify the sign of the charge on each plate.

The capacitor above is then connected electrically through a resistor to a second parallel-plate capacitor, initially uncharged, whose plates have the same area A but a separation of only s/2.

c. Indicate on the diagram below the direction of the current in each wire, and explain why the current will eventually cease.



d. After the current has ceased, which capacitor has the greater charge? Explain your reasoning.
e. The total energy stored in the two capacitors after the current has ceased is less than the initial stored energy. Explain qualitatively what has become of this "lost" energy.

ANSWERS - AP Physics Multiple Choice Practice – Circuits

	Solution	Answer
1.	The resistances are as follows: I: 2 Ω, II: 4 Ω, III: 1 Ω, IV: 2 Ω	A,D
2.	The total resistance of the 3 Ω and 6 Ω in parallel is 2 Ω making the total circuit resistance 6 Ω and the total current $\mathcal{E}/R = 1$ A. This 1 A will divide in the ratio of 2:1 through the 3 Ω and 6 Ω respectively so the 3 Ω resistor receives 2/3 A making the potential difference IR = (2/3 A)(3 Ω) = 2 V.	A
3.	Adding resistors in parallel decreases the total circuit resistance, this increasing the total current in the circuit.	A
4.	$R = \rho L/A$. Greatest resistance is the longest, narrowest resistor.	B
5.	$P = I\mathcal{E}$	B
6.	$W = Pt = I^2Rt$	B
7.	The resistance of the two 2 Ω resistors in parallel is 1 Ω. Added to the 2 Ω resistor in series with the pair gives 3 Ω	A
8.	$R = \rho L/A$. Least resistance is the widest, shortest resistor	C
9.	The resistance of the two resistors in parallel is r/2. The total circuit resistance is then 10 Ω + ½ r, which is equivalent to $\mathcal{E}/I$ = (10 V)/(0.5 A) = 20 Ω = 10 Ω + r/2	D
10.	The loop rule involves the potential and energy supplied by the battery and it's use around a circuit loop.	B
11.	Total circuit resistance (including internal resistance) = 40 Ω; total current = 0.3 A. $\mathcal{E} = IR$	D
12.	$P = I^2r$	A
13.	With more current drawn from the battery for the parallel connection, more power is dissipated in this connection. While the resistors in series share the voltage of the battery, the resistors in parallel have the full potential difference of the battery across them.	B
14.	Resistance of the 1 Ω and 3 Ω in series = 4 Ω. This, in parallel with the 2 Ω resistor gives (2 × 4) /(2 + 4) = 8/6 Ω. Also notice the equivalent resistance must be less than 2 Ω (the 2 Ω resistor is in parallel and the total resistance in parallel is smaller than the smallest resistor) and there is only one choice smaller than 2 Ω.	A
15.	The upper branch, with twice the resistance of the lower branch, will have ½ the current of the lower branch.	D
16.	The larger loop, with twice the radius, has twice the circumference (length) and $R = \rho L/A$	C
17.	$R = \rho L/A$. If L ÷ 2, R ÷ 2 and is r ÷ 2 then A ÷ 4 and R × 4 making the net effect R ÷ 2 × 4	B
18.	The motor uses P = IV = 60 W of power but only delivers P = Fv = mgv = 45 W of power. The efficiency is "what you get" ÷ "what you are paying for" = 45/60	D
19.	Resistance of the 2000 Ω and 6000 Ω in parallel = 1500 Ω, adding the 2500 Ω in series gives a total circuit resistance of 4000 Ω. $I_{total} = I_1 = \mathcal{E}/R_{total}$	C
20.	I_1 is the main branch current and is the largest. It will split into I_2 and $I_3$and since I_2 moves through the smaller resistor, it will be larger than I_3.	A
21.	$P = V^2/R$	D

22. Current is greatest where resistance is least. The resistances are, in order, 1 Ω, 2 Ω, 4 Ω, 2 Ω and 6 Ω. A

23. See above D

24. Least power is for the greatest resistance ($P = \mathcal{E}^2/R$) D

25. $P = I^2R$ and $R = \rho L/A$ giving $P \propto \rho L/d^2$ C

26. $P = I^2R$ D

27. Total resistance = $\mathcal{E}/I = 25\ \Omega$. Resistance of the 30 Ω and 60 Ω resistors in parallel = 20 Ω adding the internal resistance in series with the external circuit gives $R_{total} = 20\ \Omega + r = 25\ \Omega$ C

28. $P = V^2/R$ and if V is constant $P \propto 1/R$ A

29. For the ammeter to read zero means the junctions at the ends of the ammeter have the same potential. For this to be true, the potential drops across the 1 Ω and the 2 Ω resistor must be equal, which means the current through the 1 Ω resistor must be twice that of the 2 Ω resistor. This means the resistance of the upper branch (1 Ω and 3 Ω) must be ½ that of the lower branch (2 Ω and R) giving 1 Ω + 3 Ω = ½ (2 Ω + R) D

30. To dissipate 24 W means $R = V^2/P = 6\ \Omega$. The resistances, in order, are: 8 Ω, 4/3 Ω, 8/3 Ω, 12 Ω and 6 Ω D

31. Dimensional analysis: 1.6×10^{-3} A = 1.6×10^{-3} C/s ÷ 1.6×10^{-19} C/proton = 10^{16} protons/sec ÷ 10^9 protons/meter = 10^7 m/s D

32. Closing the switch short circuits Bulb 2 causing no current to flow to it. Since the bulbs were originally in series, this decreases the total resistance and increases the total current, making bulb 1 brighter. B

33. $P = V^2/R$ C

34. Closing the switch reduces the resistance in the right side from 20 Ω to 15 Ω, making the total circuit resistance decrease from 35 Ω to 30 Ω, a slight decrease, causing a slight increase in current. For the current to double, the total resistance must be cut in half. B

35. $R = \rho L/A \propto L/d^2$ where d is the diameter. $R_x/R_y = L_x/d_x^2 \div L_y/d_y^2 = (2L_y)d_y^2/[L_y(2d_y)^2] = ½$ A

36. The equivalent resistance of the 20 Ω and the 60 Ω in parallel is 15 Ω, added to the 35 Ω resistor in series gives 15 Ω + 35 Ω = 50 Ω C

37. N is in the main branch, with the most current. The current then divides into the two branches, with K receiving twice the current as L and M. The L/M branch has twice the resistance of the K branch. L and M in series have the same current. C

38. See above. Current is related to brightness ($P = I^2R$) C

39. If K burns out, the circuit becomes a series circuit with the three resistors, N, M and L all in series, reducing the current through bulb N. D

40. If M burns out, the circuit becomes a series circuit with the two resistors, N and K in series, with bulb L going out as well since it is in series with bulb M. D

41. The equivalent resistance in parallel is smaller than the smallest resistance. A

42. In series, they all have the same current, 2 A. $P_3 = I_3V_3$ B

43. $P = \mathcal{E}^2/R$. Total resistance of n resistors in series is nR making the power $P = \mathcal{E}^2/nR = P/n$ D

44. The current through bulb 3 is twice the current through 1 and 2 since the branch with bulb 3 is half the resistance of the upper branch. The potential difference is the same across each branch, but bulbs 1 and 2 must divide the potential difference between them. A,B

45. $R = \rho L/A \propto L/d^2$ where d is the diameter. $R_{II}/R_I = L_{II}/d_{II}^2 \div L_I/d_I^2 = (2L_I)d_I^2/[L_I(2d_I)^2] = ½$ C

46. For the currents in the branches to be equal, each branch must have the same resistance. C

47. $R \propto L/A = L/d^2$. If d × 2, R ÷ 4 and if L ÷ 2, R ÷ 2 making the net effect R ÷ 8 A

48. Bulbs in the main branch have the most current through them and are the brightest. D

49. In parallel, all the resistors have the same voltage (2 V). $P_3 = I_3V_3$ C

50. Resistor D is in a branch by itself while resistors A, B and C are in series, drawing less current than resistor D. D

51. Each computer draws I = P/V = 4.17 A. 4 computers will draw 16.7 A, while 5 will draw over 20 A. C

52. Resistance of bulbs B & C = 20 Ω combined with D in parallel gives 6.7 Ω for the right side. Combined with A & E in series gives a total resistance of 26.7 Ω. $\mathcal{E} = IR$ B

53. A and E failing in the main branch would cause the entire circuit to fail. B and C would affect each other. A

54. V = IR A

55. $\mathcal{E} = IR_{total}$ where $R_{total} = 35\ \Omega$ C

56. With the switch closed, the resistance of the 15 Ω and the 30 Ω in parallel is 10 Ω, making the total circuit resistance 30 Ω and $\mathcal{E} = IR$ C

57. $P = I^2R$ B

58. The equivalent resistance through path ACD is equal to the equivalent resistance through path ABD, making the current through the two branches equal D

59. The resistance in each of the two paths is 9 Ω, making the current in each branch 1 A. From point A, the potential drop across the 7 Ω resistor is then 7 V and across the 4 Ω resistor is 4 V, making point B 3 V lower than point C C

60. Since the volume of material drawn into a new shape in unchanged, when the length is doubled, the area is halved. $R = \rho L/A$ D

61. Closing the switch reduces the total resistance of the circuit, increasing the current in the main branch containing bulb 1 A

62. *Resistivity* is dependent on the material. Not to be confused with *resistance* C

63. Resistors J and N are in the main branch and therefore receive the largest current. D

64. $P = I^2R$ D

65. With a total resistance of 10 Ω, the total current is 1.2 A. The terminal voltage $V_T = \mathcal{E} - Ir$ B

66. Most rapid heating requires the largest power dissipation. This occurs with the resistors in parallel. D

67. Shorting bulb 3 decreases the resistance in the right branch, increasing the current through bulb 4 and decreasing the total circuit resistance. This increases the total current in the main branch containing bulb 1. C

68. For more light at a given voltage, more current is required, which requires less resistance. $R = \rho L/A$ — B

69. Bulb C in the main branch receiving the total current will be the brightest — C

70. Wire CD shorts out bulb #3 so it will never light. Closing the switch merely adds bulb #2 in parallel to bulb #1, which does not change the potential difference across bulb #1. — C

71. Shorting bulb 4 decreases the resistance in the right branch, increasing the current through bulb 3 and in the main branch containing bulb 1. — C

72. If A were to burn out, the total resistance of the parallel part of the circuit increases, causing less current from the battery and less current through bulb A. However, A and B split the voltage from the battery in a loop and with less current through bulb A, A will have a smaller share of voltage, increasing the potential difference (and the current) through bulb B. — B

73. Since there is constant current, bulb 1 remains unchanged and bulbs 2 and three must now split the current. With half the current through bulb 2, the potential difference between A and B is also halved. — D

74. The voltmeter is essentially another resistor. The voltmeter in parallel with the 100 Ω resistor acts as a 500 Ω resistor, which will half ½ the voltage of the 100 Ω resistor on the left. Thus the 120 V will split into 80 V for the 1000 Ω resistor and 40 V for the voltmeter combination. — C

75. $P = I^2R$ and the current is the same through each resistor. — A

76. The 15 Ω resistor would be in parallel with the 30 Ω resistor when the switch is closed. — C

77. ACD = 9 Ω, ABD = 9 Ω so the total resistance is 4.5 Ω making the total current $\mathcal{E}/R$ = 2 A. — A

78. The 2 A will divide equally between the two branches with 1 A going through each branch. From B to D we have – (1 A)(2 Ω) = –2 V, with B at the higher potential — A

79. For no current to flow, the potential drop across R_1 must equal the potential drop across R_2. For this to occur $I_1R_1 = I_2R_2$. Since the two branches also have the same potential difference as a whole (they are in parallel) we also have $I_1(R_1 + R_3) = I_2(R_2 + R_4)$. Solve for R_3 — D

80. The resistances are, respectively, 4/3 R, 2/5 R, R, and 5/3 R — A

81. Closing the switch adds another parallel branch, increasing the total current delivered by the battery. Bulb 3 will get brighter. Bulb 2, in its own loop with bulb 3 and the battery will then lose some of its share of the potential difference from the battery and will get dimmer. — C

82. Using ratios, the currents in the 6 Ω and 3 Ω resistors are 1 A and 2 A. They have three times and 3/2 times the resistance of the 2 Ω resistor so they will have 1/3 and 2/3 the current. The total current is then 6 A giving a potential drop of 36 V across the 6 Ω resistor in the main branch and adding any one of the branches below with the loop rule gives 36 V + 6 V = 42 V for the battery — B

83. Voltmeters must be placed in parallel and ammeters must be placed in series. — B

84. Even though B_2 burns out, the circuit is still operating elsewhere as there are still closed paths. — B

85. With B_2 burning out, the total resistance of the circuit increases as it is now a series circuit. This decreases the current in the main branch, decreasing V_1. For V_1 to be halved, the current must be halved which means the total resistance must be doubled, which by inspection did not happen in this case (total before = 5/3 R, total after = 3 R) — C

86 S_1 must be closed to have any current. Closing S_2 will allow current in R_2 but closing R_3 would short circuit R_2. — C

87. S_1 must be closed to have any current. Closing S_3 will short circuit R_3, leaving only resistor R_1, which is the lowest possible resistance. — D

88. S_1 must be closed to have any current. The greatest voltage will occur with the greatest current through R_3 but closing S_2 or S_3 will draw current away from R_3. A

89. $R = \rho L/A$ D

90. Starting at A and summing potential differences *counterclockwise* to point C gives 12 V A

91. The branch with two 2 Ω resistors has a total resistance of 4 Ω and a potential difference of 12 V. $V = IR$ C

92. Before cutting the resistance is R. After cutting we have two wires of resistance ½ R which in parallel is an equivalent resistance of ¼ R. $P = V^2/R$ and $I = V/R$ D

93. $P = V^2/R$ and $R = \rho L/A$ giving $P = V^2A/\rho L$ B

WARNING ONLY CIRCUITS WITH RESISTORS ARE ON AP PHYSICS 1

1976B3

a. $V_T = E - Ir = 6$ V

b. In parallel, each resistor gets 6 V and $P = V^2/R$ gives $R = 3\ \Omega$

c. For the 3 Ω resistor we have $I = V/R = 2$ A leaving 1 A for the branch with R_1. $R = V/I = 6\ \Omega$

1981B4

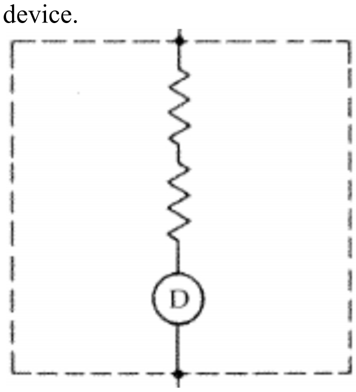
a. The two batteries are connected with opposing emfs so the total emf in the circuit is $\mathcal{E} = 60\text{ V} - 12\text{ V} = 48$ V
The resistance of the parallel combination of resistors is $(\frac{1}{4} + \frac{1}{4} + \frac{1}{2})^{-1} = 1\ \Omega$ combining with the rest of the resistors in series gives a total circuit resistance of 8 Ω.
The total current is then $\mathcal{E}/R = 6$ A. The voltage across the parallel combination of resistors is $V_P = IR_P = 6$ V so the current through the 2 Ω resistor is $I = V/R = 3$ A

b. $P = I^2R = 108$ W

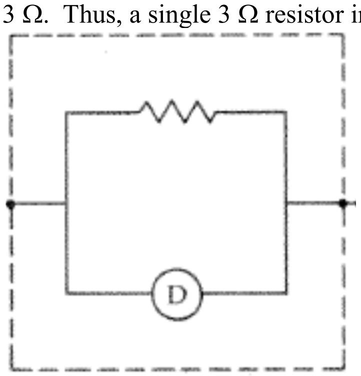
c. The current is forced through battery Bfrom the positive to the negative terminal, charging the battery. This makes the equation for the terminal voltage $V_T = \mathcal{E} + Ir = 18$ V

1980B2

a. The resistance of the device is found from $R = V/I = 6\ \Omega$. With a 24 volt source, to provide a current of 2 A requires a total resistance of 12 Ω. For the additional 6 Ω resistance, place two 3 Ω resistors in series with the device.



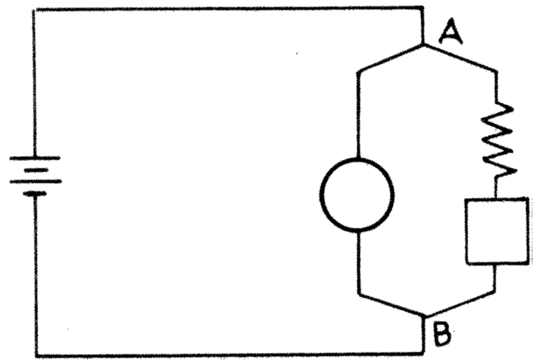
b. Since the device requires 2 A, a resistor in parallel with the device must carry a current of 6 A – 2 A = 4 A. In parallel with the device, the resistor will have a potential difference of 12 V so must have a resistance of V/I = 3 Ω. Thus, a single 3 Ω resistor in parallel will suffice.



c. $P = I^2R = 48$ W

1982B4

a. Since the clock requires 15 V it must be directly connected between A and B. Since the radio requires less than 15 V, there must be a resistor in series with it.



b. The current through the radio (and R) is 10 mA. The voltage across the radio is 9 V, which leaves 6 V across the resistor giving R = V/I = 600 Ω

c. P = IV where V = 15 V and I = 10 mA + 20 mA = 30 mA so P = 0.45 W and energy = Pt = 27 J

1983B3

a. The two batteries are connected with opposing emfs so the total emf in the circuit is $\mathcal{E}$ = 20 V – 2 V = 18 V
The equivalent resistance of the two parallel resistors is (6 × 12)/(6 + 12) = 4 Ω and since R is in series with the pair, the total circuit resistance is (4 + R) Ω = $\mathcal{E}$/I = 9 Ω giving R = 5 Ω

b. Because the voltages of the two resistors in parallel are equal we have $6I_1 = 12I_2$ and $I_1 + I_2 = 2$ A giving
   i. 4/3 A
   ii. 2/3 A

c. Summing the potential differences form point X gives $V_X + IR = 0 + (2\text{ A})(5\ \Omega) = V_B = 10$ V. Continuing along gives $V_B - 20\text{ V} = V_C = -10$ V. And $V_C + (2/3\text{ A})(12\ \Omega) = V_D = -2$ V

d. P = $\mathcal{E}$I = 40 W

1986B3

a. $P = V^2R$ gives R = 240 Ω

b. Bulbs Y and Z in parallel have an equivalent resistance of 120 Ω. Adding bulb X in series with the pair gives R = 360 Ω

c. $P_T = \mathcal{E}^2/R_T = 40$ W

d. I = $\mathcal{E}$/R = 1/3 A

e. $V_X = IR_X = 80$ V

f. The current splits equally through Y and Z. $V_Z = I_ZR_Z = (1/6\text{ A})(240\ \Omega) = 40$ V

1987B4

a. The equivalent resistance of R_1 and R_2 is (12 × 4)/(12 + 4) = 3 Ω. Adding R_3 in series with the pair gives R = 12 Ω

b. $\mathcal{E} = IR_T = 4.8$ V

c. The voltage across resistor 1 (equal to the voltage across R_2) is the emf of the battery minus the drop across R_3 which is 4.8 V – (0.4 A)(9 Ω) = 1.2 V

d. $P = V^2/R = 0.36$ W

e. Q = It = (0.4 C/s)(60 s) = 24 C

1988B3

a. On the right we have two resistors in series: 10 Ω + 2 Ω = 12 Ω. This is in parallel with the 4 Ω resistor which is an equivalent resistance of 3 Ω and adding the remaining main branch resistor in series gives a total circuit resistance of 9 Ω. The current is then $I = \mathcal{E}/R_T = 8$ A

b. The voltage remaining for the parallel branches on the right is the emf of the battery minus the potential dropped across the 6 Ω resistor which is 72 V – (8 A)(6 Ω) = 24 V. Thus the current in the 10 Ω resistor is the current through the whole 12 Ω branch which is I = V/R = (24 V)/(12 Ω) = 2 A

c. $V_{10} = I_{10}R_{10} = 20$ V

d. When charged, the capacitor is in parallel with the 10 Ω resistor so $V_C = V_{10} = 20$ V and Q = CV = 60 μC

e. $U_C = \frac{1}{2} CV^2 = 6 \times 10^{-4}$ J

1989B3

a. i. $P = I^2R = (2\text{ A})^2(10\ \Omega) = 40$ W

ii. P = Fv = mgv = 20 W (using $g = 10\text{ m/s}^2$)

iii. $P_B = P_R + P_M = 40\text{ W} + 20\text{ W} = 60$ W

b. i. V = IR = 20 V

ii. V = P/I = (20 W)/(2 A) = 10 V

iii. $\mathcal{E} = V_R + V_M = 30$ V

c. Since the speed is increased by 3/2, the voltage drop increases by the same value and is now (3/2)(10 V) = 15 V

d. The new voltage across the resistor is found from $V_R = \mathcal{E} - V_M = 15$ V and $I = V_R/I = (15\text{ V})/(2\text{ A}) = 7.5\ \Omega$

1990B3

a. The 4 Ω and 8 Ω are in series so their equivalent resistance is 12 Ω. Another 12 Ω resistor in parallel makes the equivalent resistance (12 × 12)/(12 + 12) = 6 Ω

b. Adding the remaining resistors in series throughout the circuit gives a total circuit resistance of 12 Ω and the total current (which is also the current in the 5 Ω resistor) = $\mathcal{E}$/R = 2 A

c. $V_{AC} = \mathcal{E} - Ir = 22$ V

d. The current divides equally between the two branches on the right so $P_{12} = I^2R = (1\text{ A})^2(12\ \Omega) = 12$ W

e. From B to C you only have to pass through the 12 Ω resistor which gives V = (1 A)(12 Ω) = 12 V

f. $P_B = V_{AC}^2/R_{external} = (22\text{ V})^2/11\ \Omega = 44$ W

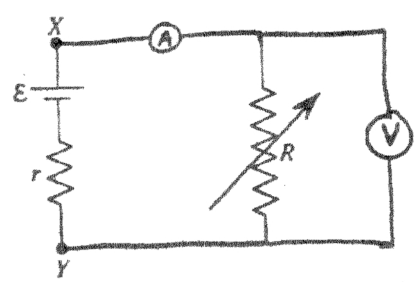
1991B4

a/b. $V_{XY} = \mathcal{E} - Ir$ and using data from the graph we can find two equations to solve simultaneously
4 V = $\mathcal{E}$ – (1 A)r and 3 V = $\mathcal{E}$ – (3 A)r will yield the solutions $\mathcal{E}$ = 4.5 V and r = 0.5 Ω

c. V_{XY} = IR which gives 3 V = (3 A)R and R = 1 Ω

d. I_{max} occurs for R = 0 and $V_{XY} = 0$ which gives $\mathcal{E} = I_{max}r$ and $I_{max} = 9$ A (this is the x intercept of the graph)

e.

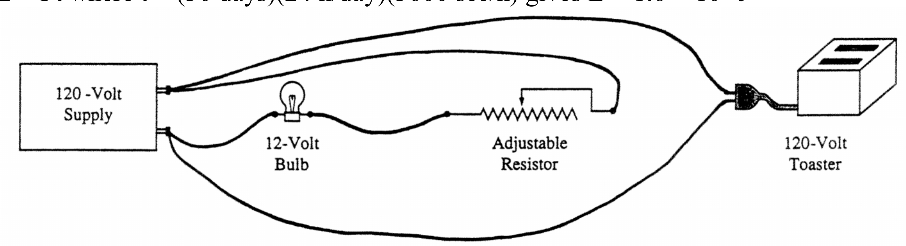


1995B2

a. $P = V^2/R$ gives $R = 24\ \Omega$

b. $E = Pt$ where t = (30 days)(24 h/day)(3600 sec/h) gives $E = 1.6 \times 10^7$ J

c.



The bulb, needing only 12 V must have a resistor in series with it and the toaster, requiring 120 V must be connected directly to the power supply.

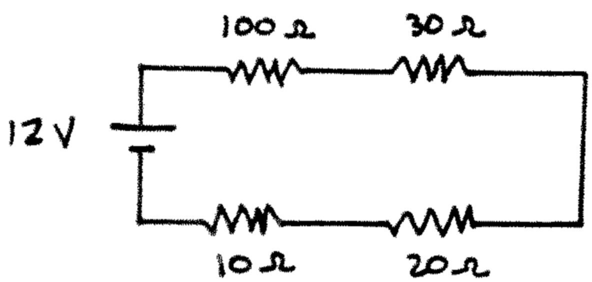
d. The current through the bulb is $I = P/V = 0.5$ A, which is also the current in the resistor, which must have 108 V across it to provide the light bulb only 12 V. $R = V/I = (108\text{ V})/(0.5\text{ A}) = 216\ \Omega$

e. i. If the resistance of the resistor is increased, the current through the branch will decrease, decreasing the brightness of the bulb.

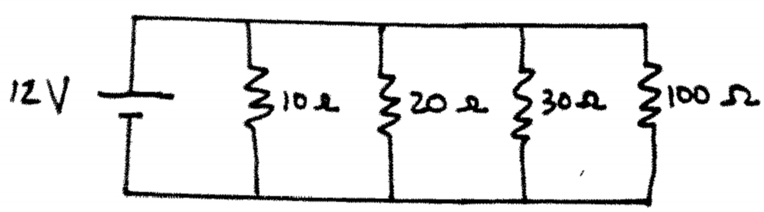
ii. Since the toaster operates in its own parallel branch, nothing will change for the toaster.

1996B4

a. For the smallest current, place the resistors in series



b. For the largest current, place the resistors in parallel



c. i. The 20 Ω and 30 Ω resistors combine in series as a 50 Ω resistor, which is in parallel with the 100 Ω resistor making their effective resistance 33.3 Ω. Adding the 10 Ω resistor in the main branch in series gives a total circuit resistance of 43 Ω. The current in the 10 Ω resistor is the total current delivered by the battery $\mathcal{E}/R = 0.28$ A

ii. $P = \mathcal{E}^2/R = 3.35$ W

d. $E = Pt$, or $t = E/P = (10 \times 10^3\text{ J})/(3.35\text{ W}) = 3 \times 10^3$ seconds

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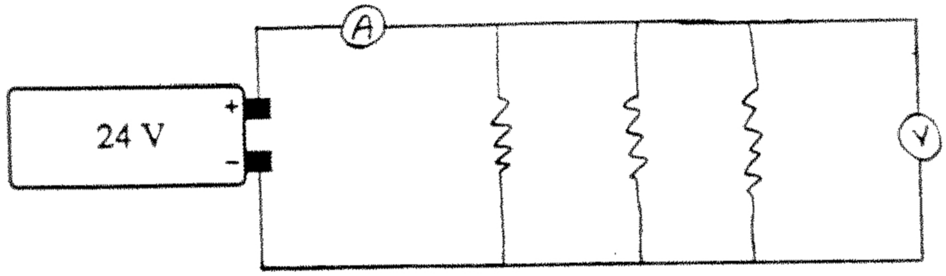
1997B4

a. i. In series $R_T = 90\ \Omega$ and $P = V^2/R = 6.4$ W

ii. In parallel $R_T = 10\ \Omega$ and $P = 57.6$ W

b. The fastest heating occurs with a parallel connection



2002B3B

a. The resistance of the 6 Ω and 3 Ω resistors in parallel is $(6 \times 3)/(6 + 3) = 2\ \Omega$. Adding the 3 Ω resistor in the main branch gives a total circuit resistance of 5 Ω. The current in bulb A in the main branch is the total current delivered by the battery $I = \mathcal{E}/R = (9\text{ V})/(5\ \Omega) = 1.8$ A

b. Bulb A is the brightest. In the main branch, it receives the most current. You can also calculate the power of each resistor where $P_A = 9.7$ W, $P_B = 2.2$ W and $P_C = 4.3$ W

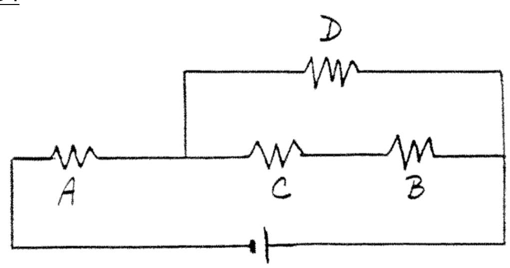
c. i. Removing Bulb C from the circuit changes the circuit to a series circuit, increasing the total resistance and decreasing the total current. With the total current decreased, bulb A is dimmer.

ii. Since bulb A receives less current, the potential drop is less than the original value and being in a loop with bulb B causes the voltage of bulb B to increase, making bulb B brighter. The current through bulb B is greater since it is no longer sharing current with bulb C.

iii. The current through bulb C is zero, bulb C goes out.

1998B4

a.



b. A > D > B = C

Bulb *A* has the largest current through it, making it brightest. The voltage across bulb *D* is the same as that across bulbs Band C combined, so it is next brightest, leaving *B* and C as least bright Bulbs *B* and C are in series, and thus have the same current through them, so they must be equally bright.

c. i. The brightness of bulb A decreases. The total resistance of the circuit increases so the current in bulb A decreases.

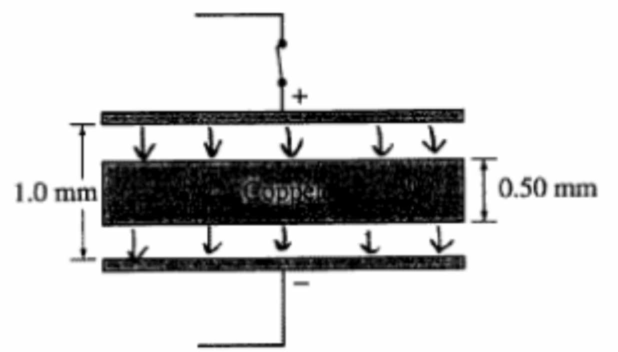
ii. The brightness of bulb B increases. The current (and the voltage) across B increases. Even though the total current decreases, it is no longer splitting to do through the branch with bulb D. Another way to look at it is since A has less current, the potential difference across A is decreased, this allows a larger share of the battery voltage to be across B and C.

2000B3

a. The equivalent resistance of the two resistors in parallel is R/2, which if ½ the resistance of the resistor in the main branch, so the parallel combination will receive half the potential difference of the main branch resistor. The 30 V of the battery will then divide into 20 V for the main branch resistor (and across the voltmeter) and 10 V each for the resistors in parallel.

b. After the switch has been closed for a long time, the voltage across the capacitor will be 30 V. $Q = CV = 3 \times 10^8$ C

c. i. The 30 V battery is still connected across the capacitor so the potential difference remains 30 V.
   ii. E = 0 inside a conductor in electrostatic equilibrium
   iii.



   iv. E = V/d and you can use the entire gap or just one of the two gaps; E = 30 V/(0.5 mm) or 15 V/(0.25 mm)
   E = 60 V/mm or 60,000 V/m

2002B3

a. i. $P = V^2/R$ gives R = 480 Ω and V = IR gives I = 0.25 A
   ii. $P = V^2/R$ gives R = 360 Ω and V = IR gives I = 0.33 A

b. i./ii. The resistances are unchanged = 480 Ω and 360 Ω. The total resistance in series is 480 Ω + 360 Ω = 840 Ω making the total current I = V/R = 0.14 A which is the same value for both resistors in series

c. The bulbs are brightest in parallel, where they provide their labeled values of 40 W and 30 W. In series, it is the larger resistor (the 30 W bulb) that glows brighter with a larger potential difference across it in series. This gives the order from top to bottom as **2 1 3 4**

d. i. In parallel, they each operate at their rated voltage so they each provide their rated power and P_T = 30 W + 40 W = 70 W
   ii. In series $P_T = V_T^2/R_T$ = 17 W

2003B2

a. For two capacitors in series the equivalent capacitance is (6 × 12)/(6 + 12) = 4 μF

b. The capacitors are fully charged so current flows through the resistors but not the capacitors. R_T = 30 Ω and I = V/R = 0.2 A

c. The potential difference between A and B is the voltage across the 20 Ω resistor. V = IR = 4 V

d. The capacitors in series store the same charge as a single 4 μF capacitor. Q = CV = (4 μF)(4 V) = 16 μC

e. Remains the same. No current is flowing from A to P to B therefore braking the circuit at point P does not affect the current in the outer loop, and therefore will not affect the potential difference between A and B.

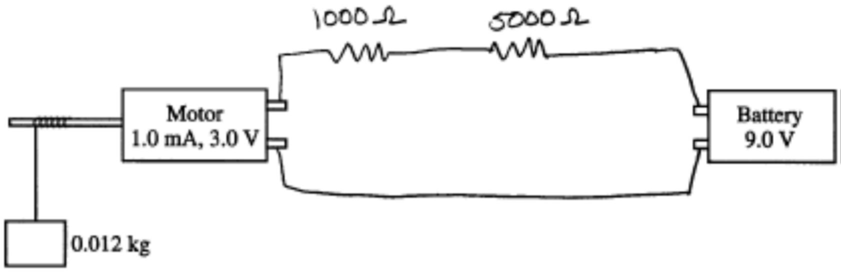
2003B2B

a. $P = IV = 3\text{ mW} = 3 \times 10^{-3}\text{ W}$

b. $E = Pt = 0.180\text{ J}$

c. e = "what you get"/"what you are paying for" = (power lifting the mass) ÷ (power provided by the motor)
$P_{lifting} = Fv = mgv = mgd/t = 1.96\text{ mW}$ so the efficiency is $1.96/3 = 0.653$ or 65.3 %

d. To reduce the battery voltage of 9 V to the motor's required voltage of 3 V, we need 6 V across the resistors. The required resistance is then $V/I = (6\text{ V})/(1\text{ mA}) = 6000\ \Omega$. This is done with a 1000 Ω and a 5000 Ω resistor in series.



2007B3

a. i. _1_ I_A _3_ I_B _2_ I_C
ii. The total current flows through R_A and gets divided between the other two resistors with the smaller resistor R_C getting a larger current

b. i. _1_ V_A _2_ V_B _2_ V_C
ii. No resistor is greater than R_A and R_A has the full current through it. R_B and R_C are in parallel and therefore have the same potential difference.

c. For the two resistors in parallel, the equivalent resistance is $(2R \times R)/(2R + R) = 2/3\ R = 133\ \Omega$. Adding R_A in series with the pair gives $R_T = 400\ \Omega + 133\ \Omega = 533\ \Omega$

d. $I_T = I_A = \mathcal{E}/R_T = 0.0225\text{ A}$. The potential drop across A is $V = IR = 9\text{ V}$ which leaves 3 V for the two branches in parallel. $I_C = V_C/R_C = 0.015\text{ A}$

e. In the new circuit, $I_B = 0$ at equilibrium and the circuit behaves as a simple series circuit with a total resistance of 600 Ω and a total current of $\mathcal{E}/R = 0.02\text{ A}$. The voltage across the capacitor is the same as the voltage across resistor C and $V_C = IR_C = 4\text{ V}$ and $Q = CV = 8 \times 10^{-6}\text{ C}$

1975E2

a. $Q = C\mathcal{E} = 12\ \mu F \times 100\text{ V} = 1200\ \mu C$

b. Connecting the two capacitors puts them in parallel with the same voltage so $V_1 = V_2$ and $V = Q/C$ which gives $Q_1/C_1 = Q_2/C_2$ or $Q_1/12 = Q_2/24$ and $Q_2 = 2Q_1$. We also know the total charge is conserved so $Q_1 + Q_2 = 1200\ \mu C$ so we have $Q_1 + 2Q_1 = 1200\ \mu C$ so $Q_1 = 400\ \mu C$

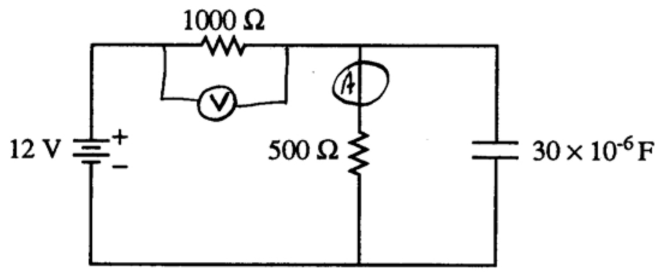
c. $V = Q/C = 33.3\text{ V}$

d. When the battery is reconnected, both capacitors charge to a potential difference of 100 V each. The total charge is then $Q = Q_1 + Q_2 = (C_1 + C_2)V = 3600\ \mu C$ making the *additional* charge from the battery 2400 μC.

2007B3B

a. In their steady states, no current flows through the capacitor so the total resistance is 1500 Ω and the total current is $\mathcal{E}/R_T = 8.0 \times 10^{-3}$ A

b.



c. The voltage across the capacitor is the same as the voltage across the 500 Ω resistor = IR = 4 V so we have $Q = CV = 1.2 \times 10^{-4}$ C

d. $P = I^2R = 6.4 \times 10^{-2}$ W

e. Larger. Replacing the 50 Ω resistor with a larger resistor lowers the steady state current, causing the voltage across the 1000 Ω resistor to decrease and the voltage across the replacement resistor to increase.

1988E2

a. In their steady states, no current flows through the capacitor so the effective resistance of the branch on the right is 8 Ω + 4 Ω = 12 Ω. This is in parallel with the 4 Ω resistor making their effective resistance (12 × 4)/(12 + 4) = 3 Ω. Adding the 9 Ω resistor in the main branch gives a total circuit resistance of 12 Ω and a total current of $\mathcal{E}/R$ = 10 A. This is the current in the 9 Ω resistor as it is in the main branch.

b. With 10 A across the 9 Ω resistor, the potential drop across it is 90 V, leaving 30 V across the two parallel branches on the right. With 30 V across the 12 Ω effective resistance in the right branch, we have a current through that branch (including the 8 Ω resistor) of V/R = 2.5 A

c. $V_C = V_4 = IR = (2.5\text{ A})(4\ \Omega) = 10$ V

d. $U_C = \frac{1}{2} CV^2 = 1500\ \mu$J

1985E2

a. Immediately after the switch is closed, the capacitor begins charging with current flowing to the capacitor as if it was just a wire. This short circuits R_2 making the total effective resistance of the circuit $5 \times 10^6\ \Omega$ and the total current $\mathcal{E}/R_{eff} = 0.006$ A

b. When the capacitor is fully charged, no current flows through that branch and the circuit behaves as a simple series circuit with a total resistance of $15 \times 10^6\ \Omega$ and a total current of $\mathcal{E}/R = 0.002$ A

c. The voltage across the capacitor is equal to the voltage across the 10 MΩ resistor as they are in parallel. $V_C = V_{10M} = IR = 2000$ V and Q = CV = 0.01 C

d. $U_C = \frac{1}{2} CV^2 = 10$ J

1986E2

a. The resistance of the two parallel branches are equal at 40 Ω each making the equivalent resistance of the two branches 20 Ω. Adding the 5 Ω resistance in the main branch gives a total circuit resistance of 25 Ω and a total current of $\mathcal{E}/R$ = 1 A which will split evenly between the two equal branches giving $I_R = 0.5$ A

b. After the capacitor is charged, no current flows from A to B, making the circuit operate as it did initially when the capacitor was not present. Therefore the current through R is the same as calculated above at 0.5 A

c. Consider the voltage at the junction above resistor R. The potential drop from this point to point A is V = IR = (0.5 A)(10 Ω) = 5 V and to point B is (0.5 A)(30 Ω) = 15 V making the potential difference across the plates of the capacitor 15 V – 5 V = 10 V. Q = CV = (10 μF)(10 V) = 100 μC

1989E3

a. When charged, the potential difference across the capacitor is 20 V. $U_C = ½\, CV^2 = 1200\ \mu J$

b. Given that the charge is initially unchanged, the work done is the change in the energy stored in the capacitor. Increasing the distance between plates to 4 times the initial value causes the capacitance to decrease to ¼ its initial value ($C \propto 1/d$). Since $Q_i = Q_f$ we have $C_iV_i = C_fV_f$ so $V_f = 4V_i$
$W = \Delta U_C = ½\, C_fV_f^2 – ½\, C_iV_i^2 = ½\, (¼\, C(4V)^2) – ½\, CV^2 = 3600\ \mu J$

c. After the spacing is increased, the capacitor acts as a battery with a voltage of 4V = 80 V with its emf opposite that of the 20 V battery making the effective voltage supplied to the circuit 80 V – 20 V = 60 V.
$I = \mathcal{E}_{eff}/R = 2 \times 10^{-4}$ A

d. The charge on the capacitor initially was $Q = CV = 120\ \mu C$ and after the plates have been separated and a new equilibrium is reach $Q = (¼C)V = 30\ \mu C$ so the charge that flowed back through the battery is $120\ \mu C – 30\ \mu C = 90\ \mu C$

e. For the battery $U = Q_{added}V = 1800\ \mu J$

1992E2

a. i. $Q = CV = 4 \times 10^{-3}$ C
   ii. $U_C = ½\, CV^2 = 4$ J

b. When the switch is closed, there is no charge on the 6 μF capacitor so the potential difference across the resistor equals that across the 2 μF capacitor, or 2000 V and $I = V/R = 2 \times 10^{-3}$ A

c. In equilibrium, charge is no longer moving so there is no potential difference across the resistor therefore the capacitors have the same potential difference. $V_2 = V_6$ gives $Q_2/C_2 = Q_6/C_6$ giving $Q_6 = 3Q_2$ and since total charge is conserved we have $Q_2 + Q_6 = Q_2 + 3Q_2 = 4Q_2 = 4 \times 10^{-3}$ C so $Q_2 = 1 \times 10^{-3}$ C and $Q_6 = 3 \times 10^{-3}$ C

d. $U_C = U_2 + U_6 = Q_2^2/2C_2 + Q_6^2/2C_6 = 1$ J. This is less than in part a. ii. Part of the energy was converted to heat in the resistor.

1995E2

a. $C = \kappa\varepsilon_0A/d$ so $\kappa = Cd/\varepsilon_0A = 5.65$

b. i. When the switch is closed, the voltage across the capacitor is zero thus all the voltage appears across the resistor and $I = \mathcal{E}/R = 1.5 \times 10^{-5}$ A

c. When fully charged, the current has stopped flowing and all the voltage now appears across the capacitor and $Q = CV = 1.5 \times 10^{-6}$ C and since the bottom plate is connected to the negative terminal of the battery the charge on that plate is also negative.

d. $U_C = ½\, CV^2 = 2.25 \times 10^{-5}$ J

e. Since the capacitor is isolated, the charge on it remains the same. Removing the plastic reduces the capacitance to $C' = \varepsilon_0A/d = C_{original}/\kappa$ and $V = Q/C' = 170$ V

f. $U' = Q^2/2C' = Q^2/2(C/\kappa) = \kappa(Q^2/2C) = \kappa U > U_{original}$. The increase came from the work that had to be done to remove the plastic from the capacitor.

1996E2

a. The initial charge on C_1 is $Q = CV_0 = 200\mu C$. In equilibrium, charge is no longer moving so there is no potential difference across the resistor therefore the capacitors have the same potential difference. $V_1 = V_2$ gives $Q_1/C_1 = Q_2/C_2$ giving $Q_2 = 3Q_1$ and since total charge is conserved we have $Q_1 + Q_2 = Q_1 + 3Q_1 = 4Q_1 = 200\ \mu C$ so $Q_1 = 50\ \mu C$ and $Q_2 = 150\ \mu C$

b. $\Delta U = U_f – U_i = (Q_1^2/2C_1 + Q_2^2/2C_2) – ½\, C_1V_0^2 = –3750\ \mu J$

2008E2

a. With a 50 Ω resistor, the right branch has a total resistance of 150 Ω, making the parallel combination with the 300 Ω resistor equal to (150 × 300)/(150 + 300) = 100 Ω. Adding R_1 from the main branch in series with the branches gives a total circuit resistance of 300 Ω and a total current of $\mathcal{E}/R$ = 5 A. The potential difference across R_1 is then V = IR = 1000V, leaving 500 V across the two parallel branches and across R_2.

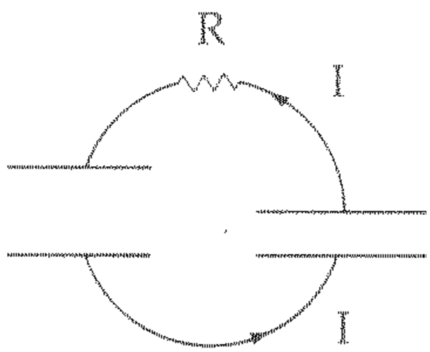
b. When the switch is closed with a capacitor between points A and B, the voltage across the capacitor is zero and the current flows through the branch as if the capacitor was a wire. This gives the effective resistance of the parallel resistors as (100 × 300)/(100 + 300) = 75 Ω and the total resistance = 275 Ω, the total current = $\mathcal{E}/R$ = 5.45 A, the voltage across R_1 = IR = 1090 V and V_2 = 1500 V – 1090 V = 410 V

1978B3

a. V = Ed = Es

b. Since the field points from the power plate to the upper plate, the lower plate is positive and the upper plate is negative.

c.



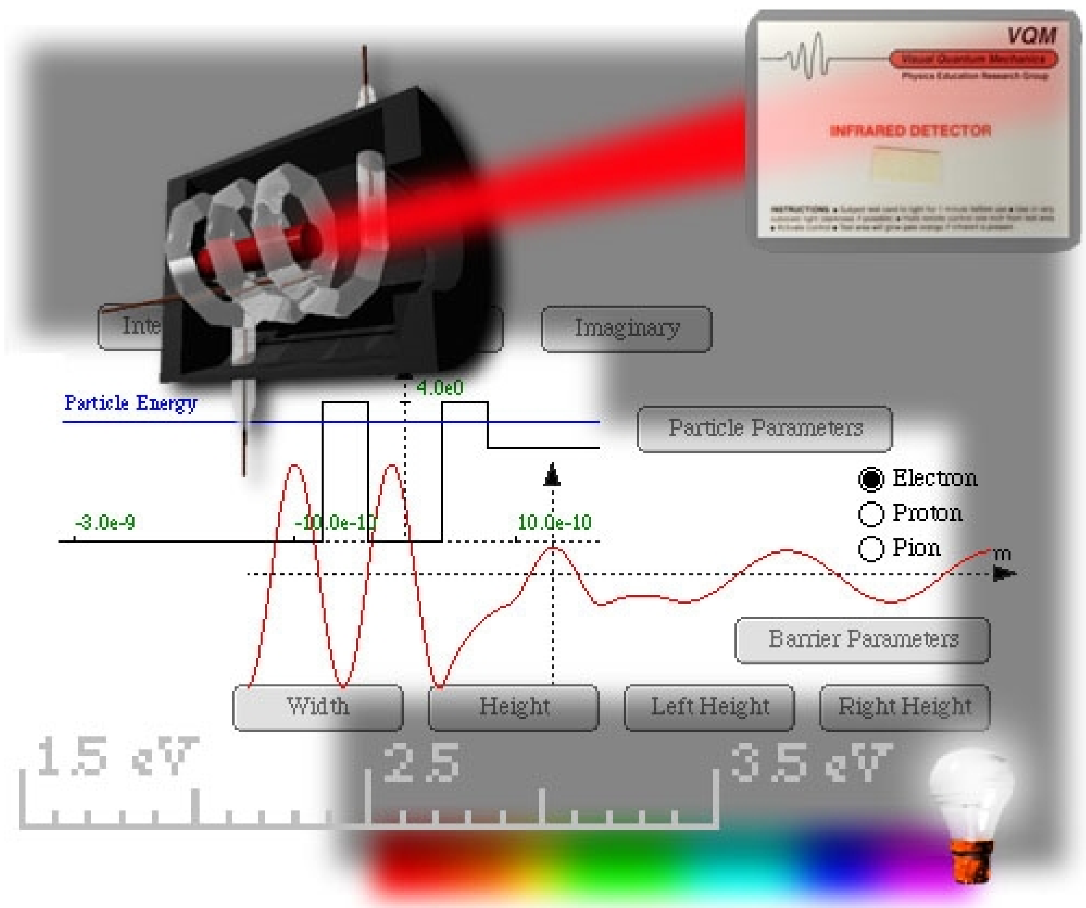
When the potential difference is the same on the two capacitors, charge will stop flowing as charge will flow only when there is a difference in potential.

d. The capacitor on the left has the smaller capacitance and since the two capacitors are in parallel, they have the same voltage. Q = CV so the larger capacitor (on the right) contains more charge.

e. The energy lost has been converted to heat through the resistor.

APPENDIX 1

Experimental Questions



AP LAB-BASED QUESTIONS

MECHANICS

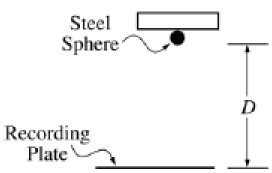
KINEMATICS (2006B2) A world-class runner can complete a 100 m dash in about 10 s. Past studies have shown that runners in such a race accelerate uniformly for a time t_u and then run at constant speed for the remainder of the race. A world-class runner is visiting your physics class. You are to develop a procedure that will allow you to determine the uniform acceleration a_u and an approximate value of t_u for the runner in a 100 m dash. By necessity your experiment will be done on a straight track and include your whole class of eleven students.

a. By checking the line next to each appropriate item in the list below, select the equipment, other than the runner and the track that your class will need to do the experiment.

_____ Stopwatches _____Tape measures _____Rulers _____Masking tape
_____Metersticks _____Starter's pistol _____String _____Chalk

b. Outline the procedure that you would use to determine a_u and t_u , including a labeled diagram of the experimental setup. Use symbols to identify carefully what measurements you would make and include in your procedure how you would use each piece of the equipment you checked in part (a).

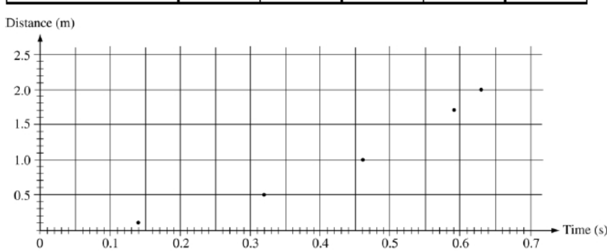
c. Outline the process of data analysis, including how you will identify the portion of the race that has uniform acceleration, and how you would calculate the uniform acceleration.



KINEMATICS (FREE FALL) (2006bB1) A student wishing to determine experimentally the acceleration g due to gravity has an apparatus that holds a small steel sphere above a recording plate, as shown above. When the sphere is released, a timer automatically begins recording the time of fall. The timer automatically stops when the sphere strikes the recording plate.

The student measures the time of fall for different values of the distance D shown above and records the data in the table below. These data points are also plotted on the graph.

Distance of Fall (m)	0.10	0.50	1.00	1.70	2.00
Time of Fall (s)	0.14	0.32	0.46	0.59	0.63



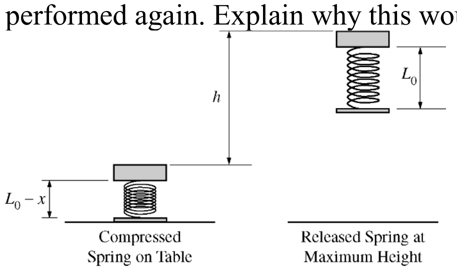
a. On the grid, sketch the smooth curve that best represents the student's data. The student can use these data for distance D and time t to produce a second graph from which the acceleration g due to gravity can be determined.

b. If only the variables D and t are used, what quantities should the student graph in order to produce a linear relationship between the two quantities?

c. Plot the data points for the quantities you have identified in part (b), and sketch the best straight-line fit to the points. Label your axes and show the scale that you have chosen for the graph.

d. Using the slope of your graph in part (c), calculate the acceleration g due to gravity in this experiment.

e. State one way in which the student could improve the accuracy of the results if the experiment were to be performed again. Explain why this would improve the accuracy.



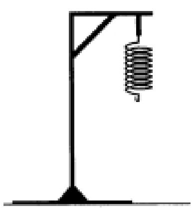
ENERGY (2009 B1) In an experiment, students are to calculate the spring constant k of a vertical spring in a small jumping toy that initially rests on a table. When the spring in the toy is compressed a distance x from its uncompressed length L_0 and the toy is released, the top of the toy rises to a maximum height h above the point of maximum compression.

The students repeat the experiment several times, measuring h with objects of various masses taped to the top of the toy so that the combined mass of the toy and added objects is m.

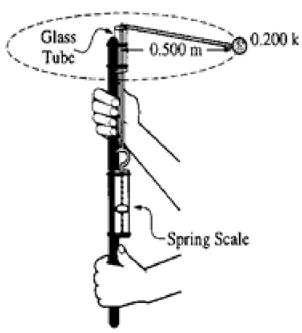
The bottom of the toy and the spring each have negligible mass compared to the top of the toy and the objects taped.
a. Derive an expression for the height h in terms of m, x, k, and fundamental constants.
With the spring compressed a distance $x = 0.020$ m in each trial, the students obtained the following data for different values of m.

	m (kg)	h (m)	
	0.020	0.49	
	0.030	0.34	
	0.040	0.28	
	0.050	0.19	
	0.060	0.18	

b. i. What quantities should be graphed so that the slope of a best-fit straight line through the data points can be used to calculate the spring constant k
ii. Fill in one or both of the blank columns in the table with calculated values of your quantities, including units.
c. Plot your data and draw a best-fit straight line. Label the axes and indicate the scale.
d. Using your best-fit line, calculate the numerical value of the spring constant. *(524 N/m)*
e. Describe a procedure for measuring the height h in the experiment, given that the toy is only momentarily at that maximum height.



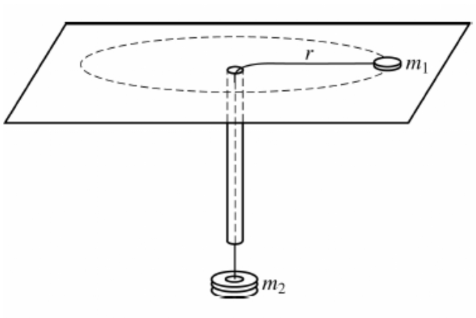
SPRINGS (1996B2)
A spring that can be assumed to be ideal hangs from a stand, as shown above.
a. You wish to determine experimentally the spring constant **k** of the spring by two different methods.
i. What additional, commonly available equipment would you need for each method?
ii. What measurements would you make in each method?
iii. How would ***k*** be determined from these measurements?
b. What quantities were graphed to make a straight-line graph for each method?



Not Necessarily To Scale

CIRCULAR MOTION 1 (1997B2)
To study circular motion, two students use the hand-held device shown, which consists of a rod on which a spring scale is attached.
A polished glass tube attached at the top serves as a guide for a light cord attached the spring scale.
A rubber stopper is attached to the other end of the cord. One student swings the teal around at constant speed in a horizontal circle with a constant radius. Assume friction and air resistance al negligible.
a. Explain how the students, by using a stopwatch and the information given above, can determine the speed of the stopper as it is revolving.
b. The students find that, despite their best efforts, they cannot swing the stopper so that the cord remains exactly horizontal.

i. Draw and label vectors to represent the forces acting on the ball
ii. Explain what measurements you need to make to determine the angle that the cord makes with the horizontal.
c. Perform the experiment by substituting the spring scale for five different masses.
d. Calculate the centripetal force, tangential velocity and centripetal acceleration for each case.
e. Neatly plot graphs of:
i. $\mathbf{F_c}$ vs $\mathbf{a_c}$ **ii.** $\mathbf{v^2}$ vs $\mathbf{a_c}$
f. Calculate the slopes for each graph. Clearly mark the points selected on the graph. Show all your calculations below. What do the slopes of each graph represent?



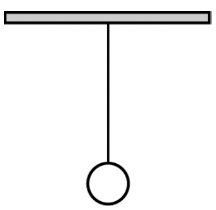
CIRCULAR MOTION 2 (2009 B1b) An experiment is performed using the apparatus above. A small disk of mass m_1 on a frictionless table is attached to one end of a string. The string passes through a hole in the table and an attached narrow, vertical plastic tube. An object of mass m_2 is hung at the other end of the string. A student holding the tube makes the disk rotate in a circle of constant radius r, while another student measures the period P.

a. Derive the equation $P = 2\pi\sqrt{\dfrac{m_1 r}{m_2 g}}$ that relates P and m_2.

The procedure is repeated, and the period P is determined for four different values of m_2, where $m_1 = 0.012$ kg and $r = 0.80$ m. The data, which are presented below, can be used to compute an experimental value for g.

m_2 (kg)	0.020	0.040	0.060	0.080
P (s)	1.40	1.05	0.80	0.75

b. What quantities should be graphed to yield a straight line with a slope that could be used to determine g?
c. Plot the quantities determined in part **(b),** label the axes, and draw the best-fit line to the data. You may use the blank rows above to record any values you may need to calculate.
d. Use your graph to calculate the experimental value of g.

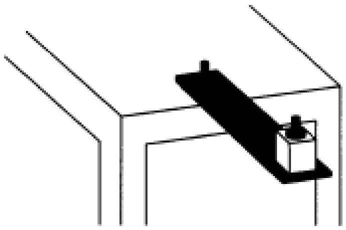


PENDULUM (2010bB2) The simple pendulum above consists of a bob hanging from a light string. You wish to experimentally determine the frequency of the swinging pendulum.
a. By checking the line next to each appropriate item on the list below, select the equipment that you would need to do the experiment.

____ Meterstick ____ Protractor ____ Additional string
____ Stopwatch ____ Photogate ____ Additional masses

b. Describe the experimental procedure that you would use. In your description, state the measurements you would make, how you would use the equipment to make them, and how you would determine the frequency from those measurements.
c. You next wish to discover which parameters of a pendulum affect its frequency. State one parameter that could be varied, describe how you would conduct the experiment, and indicate how you would analyze the data to show whether there is a dependence.
d. After swinging for a long time, the pendulum eventually comes to rest. Assume that the room is perfectly thermally insulated. How will the temperature of the room change while the pendulum comes to rest? Justify your answer.
____ It would slightly increase ____ It would slightly decrease ____ No effect. It would remain the same

e. Another pendulum using a thin, light, metal rod instead of a string is used in a clock to keep time. If the temperature of the room was to increase significantly, what effect, if any, would this have on the period of the pendulum? Justify your answer.
____ It would increase ____ It would decrease ____ No effect. It would remain the same

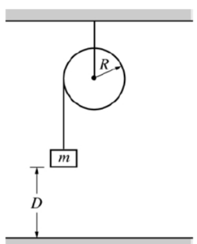


FORCE CONSTANT (1996M1) A thin, flexible metal plate attached at one end to a platform, as shown above, can be used to measure mass. When the free end of the plate is pulled down and released, it vibrates in simple harmonic motion with a period that depends on the mass attached to the plate.
To calibrate the force constant, objects of known mass are attached to the plate and the plate is vibrated, obtaining the data shown.

a. The data obtained in the experiment is shown in the table. Calculate the period.

Mass (kg)	t_{avg} for 10 vibrations (s)	T (s)	
0.10	8.86		
0.20	10.6		
0.30	13.5		
0.40	14.7		
0.50	17.7		

b. Complete the last column in the table by calculating the quantity that needs to be graphed to provide a linear relationship from the data collected.
c. Sketch a graph of the best straight-line fit to the data points.
d. From your graph clearly calculate the force constant of the metal plate.



ROTATIONAL INERTIA (2004M2) A solid disk of unknown mass and known radius ***R*** is used as a pulley in a lab experiment, as shown. A small block of mass ***m*** is attached to a string, the other end of which is attached to the pulley and wrapped around it several times.
The block of mass ***m*** is released from rest and takes a time ***t*** to fall the distance ***D*** to the floor.

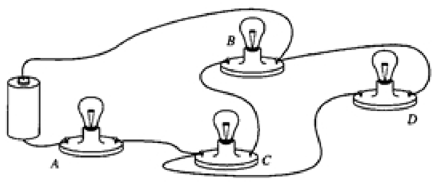
a. Calculate the **linear acceleration** *a* of the falling block in terms of the given quantities.
b. The time *t* is measured for various heights *D* and the data are recorded in the following table.

D (m)	t (s)
0.5	0.68
1	1.02
1.5	1.19
2	1.38

i. What quantities should be graphed in order to best determine the **acceleration** of the block? Explain your reasoning.
ii. Plot the quantities determined in **(b) i**., label the axes, and draw the best-fit line to the data.
iii. Use your graph to calculate the magnitude of the **acceleration**.

c. Calculate the **rotational inertia** of the pulley in terms of ***m***, ***R***, ***a***, and fundamental constants.
d. The value of acceleration found in **(b)iii,** along with numerical values for the given quantities and your answer to **(c),** can be used to determine the rotational inertia of the pulley. The pulley is removed from its support and its rotational inertia is found to be **greater** than this value. Give **one explanation** for this discrepancy.

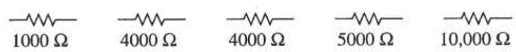
ELECTRICITY



DC CIRCUITS (1998B4) In the circuit shown, A, B. C, and D are identical light bulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each light bulb remains constant.

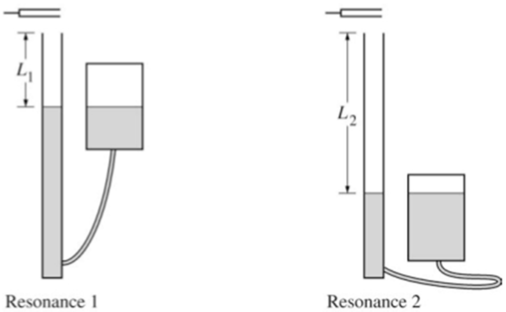
a. Draw a diagram of the circuit in the box below. **Use and label** the resistors symbols as A, B. C, and D to refer to the corresponding light bulbs.
b. List the bulbs in order of brightness, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. **Justify your answer.**
c. Bulb D is then removed from its socket.
 i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. **Justify your answer.**
 ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. **Justify your answer.**

CIRCUITS (2003Bb2) A student is asked to design a circuit to supply an electric motor with 1.0 mA of current at 3.0 V potential difference.
a. Determine the power to be supplied to the motor.
b. Determine the electrical energy to be supplied to the motor in 60 s.
c. Operating as designed above, the motor can lift a 0.012 kg mass a distance of 1.0 m in 60 s at constant velocity. Determine the efficiency of the motor.
To operate the motor, the student has available only a 9.0 V battery to use as the power source and the following five resistors.



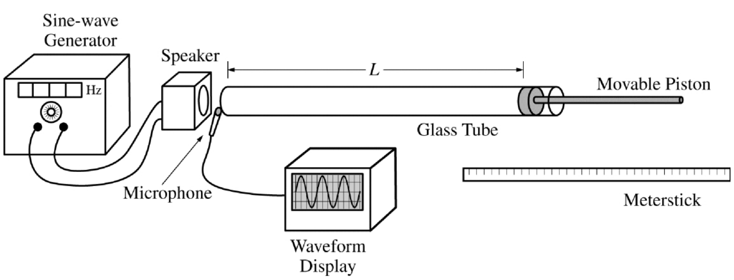
d. In the space below, complete a schematic diagram of a circuit that shows how one or more of these resistors can be connected to the battery and motor so that 1.0 mA of current and 3.0 V of potential difference are supplied to the motor. Be sure to label each resistor in the circuit with the correct value of its resistance.

WAVES AND SOUND



SPEED OF SOUND (2004Bb3)
A vibrating tuning fork is held above a column of air, as shown in the diagrams above. The reservoir is raised and lowered to change the water level, and thus the length of the column of air. The shortest length of air column that produces a resonance is $L_1 = 0.25$ m, and the next resonance is heard when the air column is $L_2 = 0.80$ m long. The speed of sound in air at 20°C is 343 m/s and the speed of sound in water is 1490 m/s.

a. Calculate the wavelength of the standing sound wave produced by this tuning fork.
b. Calculate the frequency of the tuning fork that produces the standing wave, assuming the air is at 20°C.
c.Calculate the wavelength of the sound waves produced by this tuning fork in the water.
d.The water level is lowered again until a third resonance is heard. Calculate the length L_3 of the air column that produces this third resonance.
e. The student performing this experiment determines that the temperature of the room is actually slightly higher than 20°C. Is the calculation of the frequency in part (b) too high, too low, or still correct? _____Too high _____Too low _____Still correct **Justify your answer.**



SPEED OF SOUND (2012B6) You are given the apparatus represented in the figure. A glass tube is fitted with a movable piston that allows the indicated length L to be adjusted.

A sine-wave generator with an adjustable frequency is connected to a speaker near the open end of the tube. The output of a microphone at the open end is connected to a waveform display. You are to use this apparatus to measure the speed of sound in air.
a. Describe a procedure using the apparatus that would allow you to determine the speed of sound in air. Clearly indicate what quantities you would measure and with what instrument each measurement would be made. Represent each measured quantity with a different symbol.
b. Using the symbols defined in part **(a),** indicate how your measurements can be used to determine an experimental value of the speed of sound.
c. A more accurate experimental value can be obtained by varying one of the measured quantities to obtain multiple sets of data. Indicate one quantity that can be varied, and describe how a graph of the resulting data could be used to determine the speed of sound. Clearly identify independent and dependent variables, and indicate how the slope of the graph relates to the speed of sound.