PHYSICS TOPICAL:

Electrostatics and Electromagnetism Test 1

Time: 21 Minutes*
Number of Questions: 16

* The timing restrictions for the science topical tests are optional. If you are using this test for the sole purpose of content reinforcement, you may want to disregard the time limit.

DIRECTIONS: Most of the questions in the following test are organized into groups, with a descriptive passage preceding each group of questions. Study the passage, then select the single best answer to each question in the group. Some of the questions are not based on a descriptive passage; you must also select the best answer to these questions. If you are unsure of the best answer, eliminate the choices that you know are incorrect, then select an answer from the choices that remain. Indicate your selection by blackening the corresponding circle on your answer sheet. A periodic table is provided below for your use with the questions.

PERIODIC TABLE OF THE ELEMENTS

1																	2
H																	**He**
1.0																	4.0
3	4											5	6	7	8	9	10
Li	**Be**											**B**	**C**	**N**	**O**	**F**	**Ne**
6.9	9.0											10.8	12.0	14.0	16.0	19.0	20.2
11	12											13	14	15	16	17	18
Na	**Mg**											**Al**	**Si**	**P**	**S**	**Cl**	**Ar**
23.0	24.3											27.0	28.1	31.0	32.1	35.5	39.9
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	**Ca**	**Sc**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Ge**	**As**	**Se**	**Br**	**Kr**
39.1	40.1	45.0	47.9	50.9	52.0	54.9	55.8	58.9	58.7	63.5	65.4	69.7	72.6	74.9	79.0	79.9	83.8
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Tc**	**Ru**	**Rh**	**Pd**	**Ag**	**Cd**	**In**	**Sn**	**Sb**	**Te**	**I**	**Xe**
85.5	87.6	88.9	91.2	92.9	95.9	(98)	101.1	102.9	106.4	107.9	112.4	114.8	118.7	121.8	127.6	126.9	131.3
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	**Ba**	**La** *	**Hf**	**Ta**	**W**	**Re**	**Os**	**Ir**	**Pt**	**Au**	**Hg**	**Tl**	**Pb**	**Bi**	**Po**	**At**	**Rn**
132.9	137.3	138.9	178.5	180.9	183.9	186.2	190.2	192.2	195.1	197.0	200.6	204.4	207.2	209.0	(209)	(210)	(222)
87	88	89	104	105	106	107	108	109									
Fr	**Ra**	**Ac** †	**Rf**	**Ha**	**Unh**	**Uns**	**Uno**	**Une**									
(223)	226.0	227.0	(261)	(262)	(263)	(262)	(265)	(267)									

	58	59	60	61	62	63	64	65	66	67	68	69	70	71
*	**Ce**	**Pr**	**Nd**	**Pm**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
	140.1	140.9	144.2	(145)	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.0	175.0
	90	91	92	93	94	95	96	97	98	99	100	101	102	103
†	**Th**	**Pa**	**U**	**Np**	**Pu**	**Am**	**Cm**	**Bk**	**Cf**	**Es**	**Fm**	**Md**	**No**	**Lr**
	232.0	(231)	238.0	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(260)

Passage I (Questions 1–5)

The following experiment was performed by J. J. Thomson in order to measure the ratio of the charge *e* to the mass *m* of an electron. Figure 1 shows a modern version of Thomson's apparatus.

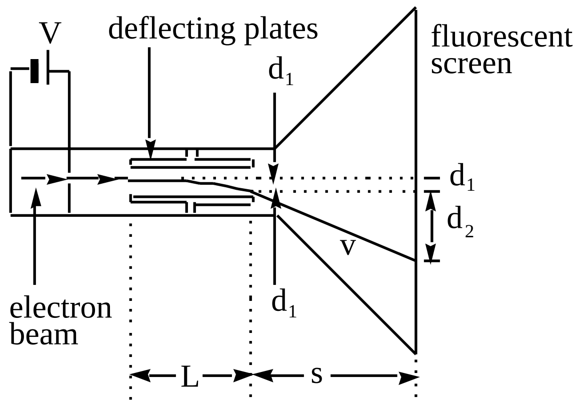

Figure 1

Electrons emitted from a hot filament are accelerated by a potential difference *V*. As the electrons pass through the deflector plates, they encounter both electric and magnetic fields. When the electrons leave the plates they enter a field-free region that extends to the fluorescent screen. The beam of electrons can be observed as a spot of light on the screen. The entire region in which the electrons travel is evacuated with a vacuum pump.

Thomson's procedure was to first set both the electric and magnetic fields to zero, note the position of the undeflected electron beam on the screen, then turn on only the electric field and measure the resulting deflection. The deflection of an electron in an electric field of magnitude E is given by $d_1 = eEL^2/2mv^2$, where L is the length of the deflecting plates, and v is the speed of the electron. The deflection d_1 can also be calculated from the total deflection of the spot on the screen, $d_1 + d_2$, and the geometry of the apparatus.

In the second part of the experiment, Thomson adjusted the magnetic field so as to exactly cancel the force applied by the electric field, leaving the electron beam undeflected. This gives $eE = evB$. By combining this relation with the expression for d_1, one can calculate the charge to mass ratio of the electron as a function of the known quantities. The result is:

$$\frac{e}{m} = \frac{2d_1E}{B^2L^2}$$

1. Why was it important for Thomson to evacuate the air from the apparatus?

A. Electrons travel faster in a vacuum, making the deflection d_1 smaller.
B. Electromagnetic waves propagate in a vacuum.
C. The electron collisions with the air molecules cause them to be scattered, and a focused beam will not be produced.
D. It was not important and could have been avoided.

2. One might have considered a different experiment in which no magnetic field is needed. The ratio *e/m* can then be calculated directly from the expression for d_1. Why might Thomson have introduced the magnetic field B in his experiment?

A. To verify the correctness of the equation for the magnetic force.
B. To avoid having to measure the electron speed *v*.
C. To cancel unwanted effects of the electric field E.
D. To make sure that the electric field does not exert a force on the electron.

3. If the electron speed were doubled by increasing the potential difference *V*, which of the following would have to be true in order to correctly measure *e/m*?

A. The magnetic field would have to be cut in half in order to cancel the force applied by the electric field.
B. The magnetic field would have to be doubled in order to cancel the force applied by the electric field.
C. The length of the plates, *L*, would have to be doubled to keep the deflection, d_1, from changing.
D. Nothing needs to be changed.

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4 . The potential difference V, which accelerates the electrons, also creates an electric field. Why did Thomson NOT consider the deflection caused by this electric field in his experiment?

A . This electric field is much weaker than the one between the deflecting plates and can be neglected.
B . Only the deflection, $d_1 + d_2$ caused by the deflecting plates is measured in the experiment.
C . There is no deflection from this electric field.
D . The magnetic field B cancels the force caused by this electric field.

5 . If the electron is deflected downward when only the electric field is turned on (as shown in Figure 1), then in what directions do the electric and magnetic fields point in the second part of the experiment?

A . The electric field points to the bottom, while the magnetic field points into the page.
B . The electric field points to the bottom, while the magnetic field points out of the page.
C . The electric field points to the top, while the magnetic field points into the page.
D . The electric field points to the top, while the magnetic field points out of the page.

GO ON TO THE NEXT PAGE.

Questions 6 through 10 are **NOT** based on a descriptive passage.

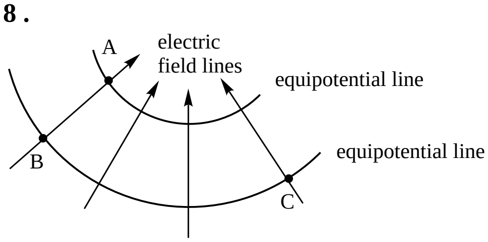
6. Charge Q experiences an attractive force of 0.25 mN (milliNewtons) when at a distance of 10 cm from a charge Q_l. It experiences a repulsive force of 0.75 mN when at a distance of 30 cm from charge Q_2. What is the ratio of Q_l / Q_2?

A. +9
B. +1/27
C. –1/9
D. –1/27

7. An electron ($e = 1.6 \times 10^{-19}$ C) is accelerated from rest by a potential difference of 5×10^{-6} V. What is the final velocity of the electron? ($m_e = 9 \times 10^{-31}$ kg)

A. $(4/3) \times 10^3$ m/s
B. $(16/9) \times 10^3$ m/s
C. $(3/4) \times 10^5$ m/s
D. $(4/3) \times 10^6$ m/s

8.



In the diagram above, which of the following differences in the electric potential are non-zero?

I. $V_C - V_B$
II. $V_C - V_A$
III. $V_B - V_A$

A. I only
B. II only
C. III only
D. II and III only

9. An electron ($q = 1.6 \times 10^{-19}$ C) is traveling at a speed of 10^5 m/s in the plane of the page, from left to right. If it passes through a magnetic field of 5 T directed out of the page, what is the magnitude and direction of the force on the electron due to the magnetic field?

A. 8×10^{-14} N towards the top of the page
B. 8×10^{-15} N towards the bottom of the page
C. 4×10^{-12} N towards the top of the page
D. 4×10^{-12} N towards the left

10. All of the following statements concerning capacitance of parallel plate capacitors are true EXCEPT:

A. The unit of capacitance, the farad, is equivalent to coulombs/volt.
B. Capacitance is directly proportional to the distance between the capacitor plates.
C. Capacitance is directly proportional to the area of the capacitor plates.
D. Each additional capacitor added in parallel increases the capacitance of the total circuit.

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Passage II (Questions 11–16)

Van de Graaff generators like the one shown in Figure 1 are used to produce very high voltages. In the figure, the + signs represent positive charge and the – signs represent negative charge. In this common Van de Graaff generator, charge is separated by the frictional contact of the belt and the lower pulley shown. Positive charge collects on the lower pulley and an equal amount of negative charge spreads out along the inside of the belt. Electrons from the ground are attracted to the outside of the belt by the net positive charge on the lower portion of the belt-pulley system. These electrons travel up the belt and are transferred to the dome, which is a hollow metal sphere. A high negative charge density can be built up on the dome, because the electrons from the outside of the belt do not experience a repulsive force from the charge built up on the outside of the sphere.

The electric potential of the dome is $V = Er$ where E is the electric field just outside the dome and r is the radius. The charges on the surface of the dome do not affect the electric field inside the cavity. The potential that can build up on the dome is limited by the dielectric strength of the air, which is about 30,000 V/cm for dry air at room temperature. When the electric field around the dome reaches the dielectric strength of the air, air molecules are ionized. This enables the air to conduct electricity.

Van de Graaff generators are routinely used in college physics laboratories. When a student gets within a few inches of a Van de Graaff generator, she may draw a spark with an instantaneous current of 10 amps and remain uninjured. An instantaneous current is the transfer of charge within 1 μs.

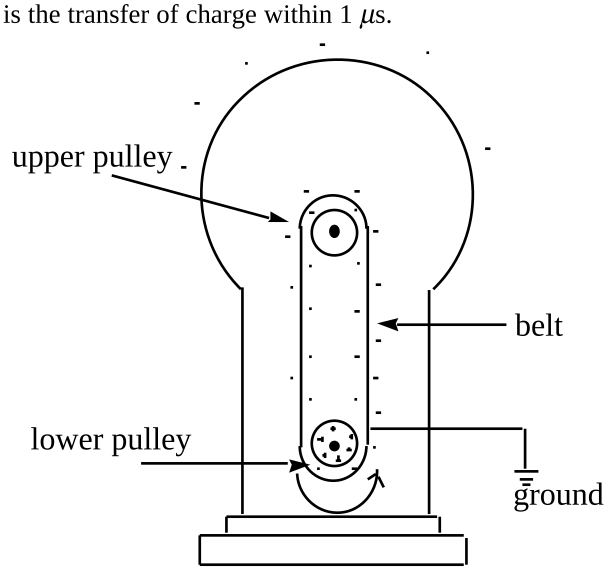

Figure 1

11. The 660 V rails on a subway can kill a person upon contact. A 10,000 V Van de Graaff generator, however, will only give a mild shock. Which of the following best explains this seeming paradox?

- **A.** The generator provides more energy per charge, but since it has few charges it transfers a lesser amount of energy.
- **B.** The generator provides more energy, but since there is little energy per charge the current is small.
- **C.** Most of the energy provided by the generator is dissipated in the air because air presents a smaller resistance than the human body.
- **D.** Most of the energy flows directly to the ground without going through the human body since the generator is grounded.

12. What is the maximum potential the dome, with a radius of 10 cm, can sustain in dry air?

- **A.** 3 kV
- **B.** 5 kV
- **C.** 300 kV
- **D.** 500 kV

13. Why is the potential of the dome limited by the dieletric strength of the air?

- **A.** Once the potential of the dome reaches the dielectric strength of the air, charge from the belt is repelled by the charge on the dome.
- **B.** Once the potential of the dome reaches the dielectric strength of the air, the air heats the metal of the dome, and it is no longer a good conductor.
- **C.** Once the air molecules become ionized, charge on the dome can leak into the air.
- **D.** Once the air molecules become ionized, they no longer conduct electricity.

14. Why does negative charge from the outside of the belt continue to build up on the outside of the dome instead of being repelled by the charge that is already there?

- **A.** The potential is zero inside the dome.
- **B.** The conducting dome shields the effects of the charges on the surface.
- **C.** There is only positive charge on the outside of the dome.
- **D.** Charge does not build up on the outside of the dome.

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15. What is the work required to move a charge q from the top of the belt to the surface of the dome, if the amount of charge on the dome is Q and q is the only charge on the belt?

A. 0
B. $kQq/2r$
C. kQq/r
D. kq/r

16. A spherical conductor with a radius of 10 cm is given a charge of –1.0 C. It is then further charged by a current of 0.5 A for three seconds, discharged, and recharged by an instantaneous current of 10 A. At what point does the sphere have the highest potential?

A. When it has a charge of –1.0 C
B. Just after being charged by the 0.5 A current
C. Just after being discharged
D. After being charged by the 10 A current

END OF TEST

ANSWER KEY:

1.	**C**	6.	**D**	11.	**A**	16.	**B**
2.	**B**	7.	**A**	12.	**C**		
3.	**A**	8.	**D**	13.	**C**		
4.	**C**	9.	**A**	14.	**B**		
5.	**D**	10.	**B**	15.	**A**		

EXPLANATIONS

Passage I (Questions 1—5)

1. C

In order to determine the charge-to-mass ratio, the deflection d_1 is an important quantity that needs to be determined. If one cannot obtain a focused beam, the deflection would not be well-defined. Choice A contains a true statement: Looking at the equation for d_1 in the passage reveals that a larger electron velocity v would indeed make d_1 smaller. This in itself, however, does not make the effect desirable. Choice B is incorrect: while it is certainly true that electromagnetic interactions can take place over a vacuum, it does not explain why it is necessary, or even beneficial, to have this condition in our set-up.

2. B

From the equation for d_1 given in the passage: $d_1 = \frac{eEL^2}{2mv^2}$, we can certainly isolate the charge-to-mass ratio and obtain an expression for it in terms of d_1, E, L, and v. This last quantity, the velocity of the electron, is hard to determine. It was the inclusion of the magnetic field that allowed Thomson to get away with not having to determine that quantity, as can be seen from the expression given at the end of the passage. Choice A does not say anything that is obviously incorrect: the Lorentz force equation is certainly verified by the experiment. However, the passage does not state that it was Thomson's intention to verify the Lorentz force equation. This choice is weak and does not address the physics of the experiment. Choice C presents us with a statement that is contradictory to the logic of the experiment. Although the magnetic field did cancel the force created by the electric field, this force was not an unwanted effect since it enabled Thomson to calculate the deflection of the beam. Choice D is incorrect: The electric field does exert a force on the electron; it is just balanced by the force exerted by the magnetic field, resulting in zero net force (and zero deflection).

3. A

What would happen if the velocity of the electron were doubled? From the equation for the deflection, $d_1 = \frac{eEL^2}{2mv^2}$, we see that doubling v would quadruple the denominator, thus making the deflection one-quarter as large as before. Let us examine each of the choices and see if they address this change. Choice A states that the magnetic field that counters the electric field would need to be cut in half. If this were to be done, then the expression for the charge-to-mass ratio: $\frac{e}{m} = \frac{2d_1E}{B^2L^2}$ would have a denominator that is one-quarter its old value, which exactly cancels the effect of reducing the deflection appearing in the numerator. The result thus remains unchanged. Choice B, doubling the magnetic field, would increase the denominator by a factor of 4, and this would have the effect of decreasing the value of e/m to 1/4 its original value. Instead of canceling the effect of reducing deflection, it in fact exacerbates the problem. Choice C, doubling the length of the plates, will indeed keep the deflection from changing as stated. (Look again at the expression for the deflection: The length is in the numerator and the velocity is in the denominator. Both appear as a square, and so doubling both would lead to no net change in the deflection.) However, in the expression for the charge-to-mass ratio, the L factor appears again in the denominator, and since the deflection is now unchanged, doubling L would decrease the value of e/m to 1/4 its initial value.

4. C

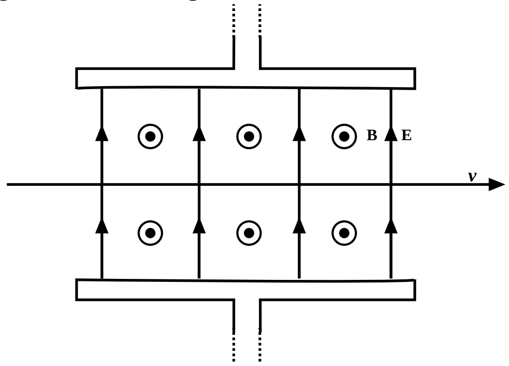
Closer examination of Figure 1 would yield the correct answer. The electrons are accelerated (anti)parallel to the electric field created by the potential difference V. The electric force is eE, where e is the charge of the electron and E is the electric field vector. There will be no sideways deflection caused by this electric field. Instead, the electrons are "deflected" from the left to the right, towards the deflecting plates.

5. D

Since the electron is deflected downward, the force on it exerted by the electric field points downward as well. For an electron, which has a negative charge, the force and the electric field point in opposite directions: the electric field therefore points upward.

To determine the direction of the magnetic field, we need the right hand rule. The electrons travel to the right. Our thumb, then, would point to the left to indicate the direction of travel of positive charges or current. The magnetic force, in order to cancel the electric force, must point upward. This is also the direction our palm would face. Our fingers then point out of the page, and this is the direction of the magnetic field.

See the following diagram for a drawing of the field directions:



Independent Questions (Questions 6—10)

6 . D

First of all, since the force between Q and Q_1 is attractive while the force between Q and Q_2 is repulsive, Q_1 and Q_2 must have opposite signs. Otherwise, the forces will be both attractive (Q_1 and Q_2 have the same sign, opposite to that of Q) or both repulsive (all three have the same sign). The ratio of Q_1 to Q_2 then will be negative. To decide between choices C and D we will have to work with the actual numbers given in the question. This is done by manipulating Coulomb's law:

$$\frac{F_1}{F_2} = \frac{\dfrac{kQ_1Q}{r_1^2}}{\dfrac{kQ_2Q}{r_2^2}}$$

$$= \frac{Q_1}{Q_2} \times \left(\frac{r_2}{r_1}\right)^2$$

$$\frac{Q_1}{Q_2} = \frac{F_1}{F_2} \times \left(\frac{r_1}{r_2}\right)^2$$

$$= -\frac{0.25}{0.75} \times \left(\frac{10}{30}\right)^2$$

$$= -\frac{1}{3} \times \left(\frac{1}{3}\right)^2$$

$$= -\frac{1}{27}$$

7 . A

The potential difference is the amount of work done by the electric field to move a unit charge, or the energy change experienced by a unit charge in this "moving process." In this case, the work done, or the energy change, is (1.6×10^{-19} C) $\times$ (5×10^{-6} V). This is the kinetic energy the electron would acquire, and since the electron starts from rest, this is also the final kinetic energy of the electron. The final velocity of the electron can thus be calculated from:

$$\frac{1}{2}\, mv^2 = (1.6 \times 10^{-19}\ \text{C}) \times (5 \times 10^{-6}\ \text{V})$$

$$v = \sqrt{\frac{2 \times (1.6 \times 10^{-19}\ \text{C}) \times (5 \times 10^{-6}\ \text{V})}{9 \times 10^{-31}\ \text{kg}}} = \sqrt{\frac{16 \times 10^{-25}}{9 \times 10^{-31}}} = \sqrt{\frac{16}{9} \times 10^{6}} = \frac{4}{3} \times 10^{3}\ \text{m/s}$$

We have not kept track of the units but simply assume that the final answer will be in terms of m/s. This is possible because all the units that go into the equation in the first place—C, V, kg—are all SI units.

8. D

Every point on an equipotential line is at the same potential; thus two points on the same line have a potential difference of zero. However, on going from one equipotential line to another, the potential difference will be non-zero. If this is still unclear, it may become clearer if we make up some numbers and associate them with the lines. Say that the equipotential line with A on it is at a 1 V potential, this will then be the potential at point A. Let the BC equipotential line be at a 2 V potential; points B and C will then both be at this potential. Then:

$$V_C - V_B = 2 - 2 = 0 \text{ V}$$
$$V_C - V_A = 2 - 1 = 1 \text{ V}$$
$$V_B - V_A = 2 - 1 = 1 \text{ V}$$

9. A

The direction of the magnetic field is determined using the right hand rule: The thumb points in the direction of qv, the fingers point in the direction of the field, and the palm points in the direction of the force. In this question, since the negatively-charged electron is going to the right, qv points in the opposite direction: to the left. The fingers should point out of the page, and thus the palm faces upward: the force is directed towards the top of the page. This eliminates choices B and D.

The magnitude of the force can be calculated via the equation $F = qvB\sin\theta$, where θ is the angle between v and B. In this case the two are perpendicular, and so the sine term is $\sin 90° = 1$. The absolute value of the electron's charge, given in the passage, is 1.6×10^{-19} C, $v = 10^5$ m/s, and B = 5 T. Multiplying these together, one gets $F = 8 \times 10^{-14}$ N.

10. B

The capacitance of a parallel-plate capacitor is given by the equation $C = \frac{\varepsilon_0 A}{d}$, where A is the area of each plate and d is the separation of the plates. The capacitance is therefore proportional to the area of the plates, and inversely proportional to the distance between them.

Capacitance has a more general definition (not limited to parallel plate ones): $C = \frac{Q}{V}$, where Q is the absolute value of the charge on either of the pair of conducting bodies making up the capacitor, and V the voltage across the two halves. From this expression we can derive the units for capacitance: charge over voltage translates into coulomb/volt, given the name of farad.

When capacitors are placed in parallel in a circuit, the total (or effective) capacitance is equal to the sum of the individual capacitances. This implies that each additional capacitor added in parallel to a circuit will increase the overall capacitance of the circuit.

Given this discussion, we can see that the statement in choice B is incorrect, and is thus the answer.

<u>Passage II</u> (Questions 11—16)

11. A

The question really tests if one understands the concept of potential. Potential is energy per unit charge. If something provides a high energy per charge, but contains relatively few charges, the total amount of energy transferred will be low. Choice B states that the generator has low energy per charge, which is untrue. Choice C attributes the safety of the generator to the dissipative effects of air, which it claims has a lower resistance than the human body. Air, in fact, has a higher resistance, and besides, the generator is discharging through the person directly, not through the air and then through the person. Choice D is incorrect because the generator is connected to ground through the belt, not the dome. If the dome itself were grounded, no charge would be able to build up. When one gets a shock from the dome one is providing the path to the ground.

12. C

In the second paragraph we are given the formula V = Er, which relates the potential on the dome, V, to the electric field just outside the dome, E, and the dome's radius. The maximum potential the dome can sustain, then, will be dictated by the maximum electric field. The dielectric strength is an indication of the maximum electric field the air can sustain. (The units for the dielectric strength given for air are volts per unit length which are the same as for electric field strength.) The maximum potential is therefore 30000 $\frac{V}{cm} \times 10$ cm = 3×10^5 V = 300 kV.

13. C

To answer this question correctly, one needs to pay close attention to the process described towards the end of the second paragraph: When the electric field of the dome reaches the value of the dielectric strength of the air around it, the air molecules become ionized. This, we are told, enables the air to conduct electricity. We can examine the answer choices one by one and see if any is consistent with the above description. Choice A states that once the potential of the dome reaches the dielectric strength of air, charge from the belt is repelled by charge on the dome. If this were true it certainly would limit the potential that can be built up, since it would limit the amount of charge that will accumulate on the dome. However, there is no reason to expect the ionization of the air molecules to bring about this repulsion that does not exist previously.

Choice B states that once the dielectric strength is reached, the air heats the metal so that it is no longer a good conductor. While it is true that as most metals heat up their conductivity decreases, the ionized air molecules would not raise the temperature of the metal significantly, if at all. So choice B is incorrect.

Choice C states that once the air molecules become ionized charge from the dome would leak out into the air. As described in the passage, once air molecules become ionized they can conduct electricity. This would provide a mechanism through which charge can leak out. This, in turn, would limit the potential on the dome since the potential is dependent on the amount of charge deposited and built up there. Choice C thus provides a reason that is both plausible and consistent with what is given in the passage.

Finally, choice D is incorrect because its statement directly contradicts what is stated in the passage.

14. B

We have a hollow metallic sphere with charge built up on the outside. It is stated in the passage that the charges on the surface do not affect the electric field in the cavity. This is because of the shielding effects of the conductor: The free electrons move in response to the field generated by the charges outside so as to cancel any effects they have. (Indeed, if the cavity itself did not hold any charges, then the electric field inside would be zero.) In this case, there is net charge present within the dome, but the important point that is still valid is that the charges that reside on the surface would not affect the interior in any way. Since they do not create any field in the cavity, they do not exert a force on any charge that is inside.

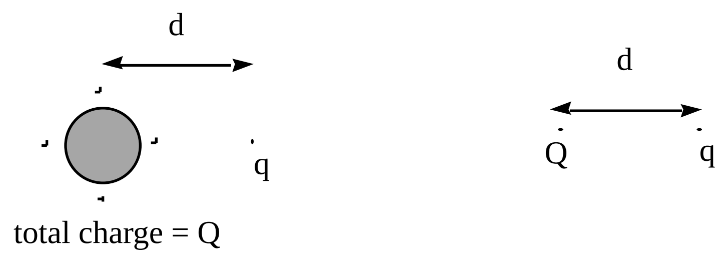
Choice A is incorrect because the potential inside the cavity is not zero. Choice C is incorrect since we are told that negative charges are transferred from the belt to the dome. Choice D is also incorrect as most of the charge will build up on the outside.

15. A

The work that needs to be done is given by the formula force $\times$ distance. In the case of moving a charge, the relevant force is the electric force $F = qE$. The electric field generated by the charge Q on the dome is shielded by the conductor, and so the presence of Q does not affect the field in the cavity. (This is also stated in the passage.) Furthermore, since q is the only charge on the belt, there are no other charges that can generate an electric field. The electric field experienced by q is thus zero. Since the electric field is zero, the force exerted is zero and consequently no work is done on the transporting of charge.

16. B

In order to answer this question, we must make use of the equation for the electrostatic potential of a charged spherical conductor given in the passage: $V = Er$. The electric field just outside the sphere, E, is kQ/r^2, where k is a constant and Q the charge on the sphere. r is in general the distance between the center of the sphere and the point at which we want to calculate the electric field; since here we are interested in the field just outside the sphere, it is the same as the radius of the sphere. Note the similarity between this and the field created by a point charge of magnitude Q: it is as if all of the charge on the sphere were compressed into a single point at the center of the sphere. I.e., in the following, the two test charges q experience the same electric field and hence the same force:



In this case, instead of a solid sphere we have a spherical shell, but this still applies. Anyway, given the expression for the electric field, we know that the potential is kQ/r. Since k and r are constants, the sphere will be at the highest potential when it has the most positive charge.

We need to determine the total charge on the sphere for each of the four answer choices and choose the one that is most positive. Choice A can be ruled out immediately since the charge is negative: it will correspond to a potential that is lower than zero (choice C). Choice B adds a positive charge with a 0.5 A current for 3 seconds. Since an ampere is a coulomb/sec, the amount of charge deposited by the current is $0.5 \times 3 = 1.5$ C. Subtracting from this the –1.0 C already present, we get +0.5 C. Choice D adds charge with an instantaneous current of 10 A. In the last paragraph of the passage, we are told that an instantaneous current acts over a period of 1 µs, or 1×10^{-6} s. The charge delivered is therefore 1×10^{-5} C. The sphere is discharged before the current is applied, and so this is also the final charge present. Choice B therefore corresponds to the point at which there is the greatest amount of charge on the sphere, and is the point of highest potential.