

4.E: Exercises

Conceptual Questions

19.1: Electric Potential Energy: Potential Difference

1. Voltage is the common word for potential difference. Which term is more descriptive, voltage or potential difference?
2. If the voltage between two points is zero, can a test charge be moved between them with zero net work being done? Can this necessarily be done without exerting a force? Explain.
3. What is the relationship between voltage and energy? More precisely, what is the relationship between potential difference and electric potential energy?
4. Voltages are always measured between two points. Why?
5. How are units of volts and electron volts related? How do they differ?

19.2: Electric Potential in a Uniform Electric Field

6. Discuss how potential difference and electric field strength are related. Give an example.
7. What is the strength of the electric field in a region where the electric potential is constant?
8. Will a negative charge, initially at rest, move toward higher or lower potential? Explain why.

19.3: Electrical Potential Due to a Point Charge

9. In what region of space is the potential due to a uniformly charged sphere the same as that of a point charge? In what region does it differ from that of a point charge?
10. Can the potential of a non-uniformly charged sphere be the same as that of a point charge? Explain.

19.4: Equipotential Lines

11. What is an equipotential line? What is an equipotential surface?
12. Explain in your own words why equipotential lines and surfaces must be perpendicular to electric field lines.
13. Can different equipotential lines cross? Explain.

19.5: Capacitors and Dielectrics

14. Does the capacitance of a device depend on the applied voltage? What about the charge stored in it?
15. Use the characteristics of the Coulomb force to explain why capacitance should be proportional to the plate area of a capacitor. Similarly, explain why capacitance should be inversely proportional to the separation between plates.
16. Give the reason why a dielectric material increases capacitance compared with what it would be with air between the plates of a capacitor. What is the independent reason that a dielectric material also allows a greater voltage to be applied to a capacitor? (The dielectric thus increases C and permits a greater V .)
17. How does the polar character of water molecules help to explain water's relatively large dielectric constant? ([Figure](#))
18. Sparks will occur between the plates of an air-filled capacitor at lower voltage when the air is humid than when dry. Explain why, considering the polar character of water molecules.
19. Water has a large dielectric constant, but it is rarely used in capacitors. Explain why.
20. Membranes in living cells, including those in humans, are characterized by a separation of charge across the membrane. Effectively, the membranes are thus charged capacitors with important functions related to the potential difference across the membrane. Is energy required to separate these charges in living membranes and, if so, is its source the metabolism of food energy or some other source?

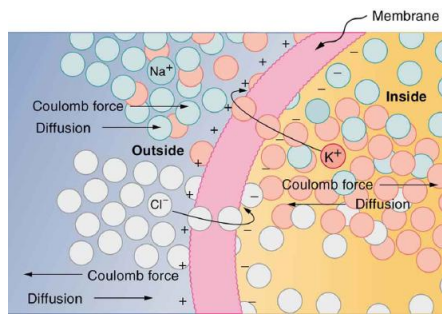


Figure 19.6.9: The semipermeable membrane of a cell has different concentrations of ions inside and out. Diffusion moves the K^+ (potassium) and Cl^- (chloride) ions in the directions shown, until the Coulomb force halts further transfer. This results in a layer of positive charge on the outside, a layer of negative charge on the inside, and thus a voltage across the cell membrane. The membrane is normally impermeable to Na^+ (sodium ions).

19.6: Capacitors in Series and Parallel

21. If you wish to store a large amount of energy in a capacitor bank, would you connect capacitors in series or parallel? Explain.

19.7: Energy Stored in Capacitors

22. How does the energy contained in a charged capacitor change when a dielectric is inserted, assuming the capacitor is isolated and its charge is constant? Does this imply that work was done?

23. What happens to the energy stored in a capacitor connected to a battery when a dielectric is inserted? Was work done in the process?

Problems & Exercises

19.1: Electric Potential Energy: Potential Difference

24. Find the ratio of speeds of an electron and a negative hydrogen ion (one having an extra electron) accelerated through the same voltage, assuming non-relativistic final speeds. Take the mass of the hydrogen ion to be $1.67 \times 10^{-27} \text{ kg}$.

Solution

42.8

25. An evacuated tube uses an accelerating voltage of 40 kV to accelerate electrons to hit a copper plate and produce x rays. Non-relativistically, what would be the maximum speed of these electrons?

26. A bare helium nucleus has two positive charges and a mass of $6.64 \times 10^{-27} \text{ kg}$

(a) Calculate its kinetic energy in joules at 2.00% of the speed of light.

(b) What is this in electron volts?

(c) What voltage would be needed to obtain this energy?

27. Integrated Concepts

Singly charged gas ions are accelerated from rest through a voltage of 13.0 V. At what temperature will the average kinetic energy of gas molecules be the same as that given these ions?

Solution

$1.00 \times 10^5 \text{ K}$

28. Integrated Concepts

The temperature near the center of the Sun is thought to be 15 million degrees Celsius ($1.5 \times 10^7^\circ \text{C}$). Through what voltage must a singly charged ion be accelerated to have the same energy as the average kinetic energy of ions at this temperature?

29. Integrated Concepts

- (a) What is the average power output of a heart defibrillator that dissipates 400 J of energy in 10.0 ms?
- (b) Considering the high-power output, why doesn't the defibrillator produce serious burns?

Solution

(a) $4 \times 10^4 \text{ W}$

(b) A defibrillator does not cause serious burns because the skin conducts electricity well at high voltages, like those used in defibrillators. The gel used aids in the transfer of energy to the body, and the skin doesn't absorb the energy, but rather lets it pass through to the heart.

30. Integrated Concepts

A lightning bolt strikes a tree, moving 20.0 C of charge through a potential difference of $1.00 \times 10^2 \text{ MV}$. (a) What energy was dissipated? (b) What mass of water could be raised from 15°C to the boiling point and then boiled by this energy? (c) Discuss the damage that could be caused to the tree by the expansion of the boiling steam.

31. Integrated Concepts

A 12.0 V battery-operated bottle warmer heats 50.0 g of glass, $2.50 \times 10^2 \text{ g}$ of baby formula, and $2.00 \times 10^2 \text{ g}$ of aluminum from 20.0°C to 90.0°C .

- (a) How much charge is moved by the battery?
- (b) How many electrons per second flow if it takes 5.00 min to warm the formula? (Hint: Assume that the specific heat of baby formula is about the same as the specific heat of water.)

Solution

(a) $7.40 \times 10^3 \text{ C}$

(b) 1.54×10^{20} electrons per second

32. Integrated Concepts

A battery-operated car utilizes a 12.0 V system. Find the charge the batteries must be able to move in order to accelerate the 750 kg car from rest to 25.0 m/s, make it climb a $2.00 \times 10^2 \text{ m}$ high hill, and then cause it to travel at a constant 25.0 m/s by exerting a $5.00 \times 10^2 \text{ N}$ force for an hour.

Solution

$3.89 \times 10^6 \text{ C}$

33. Integrated Concepts

Fusion probability is greatly enhanced when appropriate nuclei are brought close together, but mutual Coulomb repulsion must be overcome. This can be done using the kinetic energy of high-temperature gas ions or by accelerating the nuclei toward one another. (a) Calculate the potential energy of two singly charged nuclei separated by $1.00 \times 10^{-12} \text{ m}$ by finding the voltage of one at that distance and multiplying by the charge of the other. (b) At what temperature will atoms of a gas have an average kinetic energy equal to this needed electrical potential energy?

34. Unreasonable Results

- (a) Find the voltage near a 10.0 cm diameter metal sphere that has 8.00 C of excess positive charge on it.
- (b) What is unreasonable about this result?
- (c) Which assumptions are responsible?

Solution

(a) $1.44 \times 10^{12} \text{ V}$

- (b) This voltage is very high. A 10.0 cm diameter sphere could never maintain this voltage; it would discharge.
- (c) An 8.00 C charge is more charge than can reasonably be accumulated on a sphere of that size.

35. Construct Your Own Problem

Consider a battery used to supply energy to a cellular phone. Construct a problem in which you determine the energy that must be supplied by the battery, and then calculate the amount of charge it must be able to move in order to supply

this energy. Among the things to be considered are the energy needs and battery voltage. You may need to look ahead to interpret manufacturer's battery ratings in ampere-hours as energy in joules.

19.2: Electric Potential in a Uniform Electric Field

36. Show that units of V/m and N/C for electric field strength are indeed equivalent.
37. What is the strength of the electric field between two parallel conducting plates separated by 1.00 cm and having a potential difference (voltage) between them of 1.50×10^4 V?
38. The electric field strength between two parallel conducting plates separated by 4.00 cm is 7.50×10^4 V/m.
- (a) What is the potential difference between the plates?
 - (b) The plate with the lowest potential is taken to be at zero volts. What is the potential 1.00 cm from that plate (and 3.00 cm from the other)?

Solution

- (a) 3.00 kV
- (b) 750 V

39. How far apart are two conducting plates that have an electric field strength of 4.50×10^3 V/m between them, if their potential difference is 15.0 kV?
40. (a) Will the electric field strength between two parallel conducting plates exceed the breakdown strength for air (3.0×10^6 V/m) if the plates are separated by 2.00 mm and a potential difference of 5.0×10^3 V is applied?
- (b) How close together can the plates be with this applied voltage?

Solution

- (a) No. The electric field strength between the plates is 2.5×10^6 V/m which is lower than the breakdown strength for air (3.0×10^6 V/m).
- (b) 1.7 mm

41. The voltage across a membrane forming a cell wall is 80.0 mV and the membrane is 9.00 nm thick. What is the electric field strength? (The value is surprisingly large, but correct. Membranes are discussed in [Capacitors and Dielectrics](#) and [Nerve Conduction—Electrocardiograms](#).) You may assume a uniform electric field.
42. Membrane walls of living cells have surprisingly large electric fields across them due to separation of ions. (Membranes are discussed in some detail in [Nerve Conduction—Electrocardiograms](#).) What is the voltage across an 8.00 nm-thick membrane if the electric field strength across it is 5.50 MV/m? You may assume a uniform electric field.

Solution

44.0 mV

43. Two parallel conducting plates are separated by 10.0 cm, and one of them is taken to be at zero volts.
- (a) What is the electric field strength between them, if the potential 8.00 cm from the zero volt plate (and 2.00 cm from the other) is 450 V?
 - (b) What is the voltage between the plates?
44. Find the maximum potential difference between two parallel conducting plates separated by 0.500 cm of air, given the maximum sustainable electric field strength in air to be 3.0×10^6 V/m.

Solution

15 kV

45. A doubly charged ion is accelerated to an energy of 32.0 keV by the electric field between two parallel conducting plates separated by 2.00 cm. What is the electric field strength between the plates?
46. An electron is to be accelerated in a uniform electric field having a strength of 2.00×10^6 V/m.
- (a) What energy in keV is given to the electron if it is accelerated through 0.400 m?
 - (b) Over what distance would it have to be accelerated to increase its energy by 50.0 GeV?

Solution

- (a) 800 KeV
- (b) 25.0 km

19.3: Electrical Potential Due to a Point Charge

47. A 0.500 cm diameter plastic sphere, used in a static electricity demonstration, has a uniformly distributed 40.0 pC charge on its surface. What is the potential near its surface?

Solution

144 V

48. What is the potential 0.530×10^{-10} m from a proton (the average distance between the proton and electron in a hydrogen atom)?

49. (a) A sphere has a surface uniformly charged with 1.00 C. At what distance from its center is the potential 5.00 MV?

(b) What does your answer imply about the practical aspect of isolating such a large charge?

Solution

(a) 1.80 km

(b) A charge of 1 C is a very large amount of charge; a sphere of radius 1.80 km is not practical.

50. How far from a $1.00 \mu\text{C}$ point charge will the potential be 100 V? At what distance will it be 2.00×10^2 V?

51. What are the sign and magnitude of a point charge that produces a potential of -2.00 V at a distance of 1.00 mm?

Solution

-2.22×10^{-13} C

52. If the potential due to a point charge is 5.00×10^2 V at a distance of 15.0 m, what are the sign and magnitude of the charge?

53. In nuclear fission, a nucleus splits roughly in half.

(a) What is the potential 2.00×10^{-14} m from a fragment that has 46 protons in it?

(b) What is the potential energy in MeV of a similarly charged fragment at this distance?

Solution

(a) 3.31×10^6 V

(b) 152 MeV

54. A research Van de Graaff generator has a 2.00-m-diameter metal sphere with a charge of 5.00 mC on it.

(a) What is the potential near its surface?

(b) At what distance from its center is the potential 1.00 MV?

(c) An oxygen atom with three missing electrons is released near the Van de Graaff generator. What is its energy in MeV at this distance?

55. An electrostatic paint sprayer has a 0.200-m-diameter metal sphere at a potential of 25.0 kV that repels paint droplets onto a grounded object.

(a) What charge is on the sphere?

(b) What charge must a 0.100-mg drop of paint have to arrive at the object with a speed of 10.0 m/s?

Solution

(a) 2.78×10^{-7} C

(b) 2.00×10^{-10} C

56. In one of the classic nuclear physics experiments at the beginning of the 20th century, an alpha particle was accelerated toward a gold nucleus, and its path was substantially deflected by the Coulomb interaction. If the energy of the doubly charged alpha nucleus was 5.00 MeV, how close to the gold nucleus (79 protons) could it come before being deflected?

57. (a) What is the potential between two points situated 10 cm and 20 cm from a $3.0 \mu\text{C}$ point charge?

(b) To what location should the point at 20 cm be moved to increase this potential difference by a factor of two?

58. Unreasonable Results

- What is the final speed of an electron accelerated from rest through a voltage of 25.0 MV by a negatively charged Van de Graaff terminal?
- What is unreasonable about this result?
- Which assumptions are responsible?

Solution

- 2.96×10^9 m/s
- This velocity is far too great. It is faster than the speed of light.
- The assumption that the speed of the electron is far less than that of light and that the problem does not require a relativistic treatment produces an answer greater than the speed of light.

19.4: Equipotential Lines

- Sketch the equipotential lines near a point charge $+q$. Indicate the direction of increasing potential.
 - Do the same for a point charge $-3q$.

- Sketch the equipotential lines for the two equal positive charges shown in Figure 19.5.6. Indicate the direction of increasing potential.

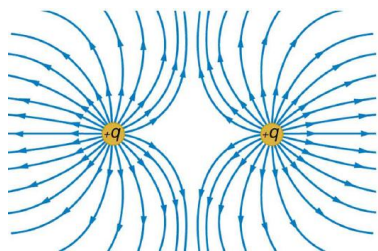
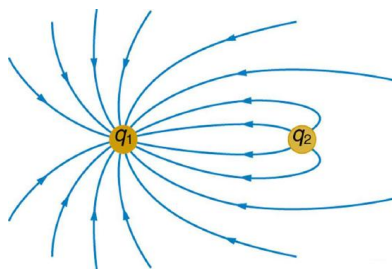


Figure 19.5.6: The electric field near two equal positive charges is directed away from each of the charges.

- Figure 19.5.7 shows the electric field lines near two charges q_1 and q_2 , the first having a magnitude four times that of the second. Sketch the equipotential lines for these two charges, and indicate the direction of increasing potential.



The electric field near two charges.

- Sketch the equipotential lines a long distance from the charges shown in Figure 19.5.7. Indicate the direction of increasing potential.
- Sketch the equipotential lines in the vicinity of two opposite charges, where the negative charge is three times as great in magnitude as the positive. See Figure 19.5.7 for a similar situation. Indicate the direction of increasing potential.
- Sketch the equipotential lines in the vicinity of the negatively charged conductor in Figure 19.5.8. How will these equipotentials look a long distance from the object?



Figure 19.5.8: A negatively charged conductor.

65. Sketch the equipotential lines surrounding the two conducting plates shown in Figure 19.5.9, given the top plate is positive and the bottom plate has an equal amount of negative charge. Be certain to indicate the distribution of charge on the plates. Is the field strongest where the plates are closest? Why should it be?

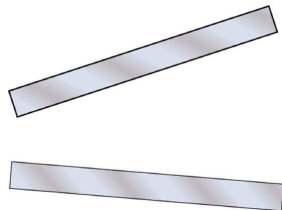


Figure 19.5.9

66. (a) Sketch the electric field lines in the vicinity of the charged insulator in Figure 19.5.10. Note its non-uniform charge distribution. (b) Sketch equipotential lines surrounding the insulator. Indicate the direction of increasing potential.

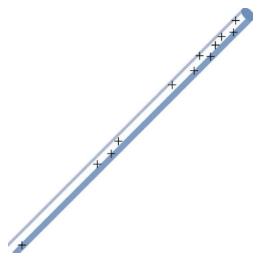


Figure 19.5.10: A charged insulating rod such as might be used in a classroom demonstration.

67. The naturally occurring charge on the ground on a fine day out in the open country is -1.00 nC/m^2 .

- What is the electric field relative to ground at a height of 3.00 m?
- Calculate the electric potential at this height.
- Sketch electric field and equipotential lines for this scenario.

68. The lesser electric ray (*Narcine bancroftii*) maintains an incredible charge on its head and a charge equal in magnitude but opposite in sign on its tail (Figure).

- Sketch the equipotential lines surrounding the ray.
- Sketch the equipotentials when the ray is near a ship with a conducting surface.
- How could this charge distribution be of use to the ray?



Figure 19.5.11: Lesser electric ray (*Narcine bancroftii*) (credit: National Oceanic and Atmospheric Administration, NOAA's Fisheries Collection).

19.5: Capacitors and Dielectrics

69. What charge is stored in a $180\ \mu\text{F}$ capacitor when $120\ \text{V}$ is applied to it?

Solution

$21.6\ \text{mC}$

70. Find the charge stored when $5.50\ \text{V}$ is applied to an $8.00\ \text{pF}$ capacitor.

71. What charge is stored in the capacitor in [Example](#)?

Solution

$80.0\ \text{mC}$

72. Calculate the voltage applied to a $2.00\ \mu\text{F}$ capacitor when it holds $3.10\ \mu\text{C}$ of charge.

73. What voltage must be applied to an $8.00\ \text{nF}$ capacitor to store $0.160\ \text{mC}$ of charge?

Solution

$20.0\ \text{kV}$

74. What capacitance is needed to store $3.00\ \mu\text{C}$ of charge at a voltage of $120\ \text{V}$?

75. What is the capacitance of a large Van de Graaff generator's terminal, given that it stores $8.00\ \text{mC}$ of charge at a voltage of $12.0\ \text{MV}$?

Solution

$667\ \text{pF}$

76. Find the capacitance of a parallel plate capacitor having plates of area $5.00\ \text{m}^2$ that are separated by $0.100\ \text{mm}$ of Teflon.

77. (a) What is the capacitance of a parallel plate capacitor having plates of area $1.50\ \text{m}^2$ that are separated by $0.0200\ \text{mm}$ of neoprene rubber?

(b) What charge does it hold when $9.00\ \text{V}$ is applied to it?

Solution

(a) $4.4\ \mu\text{F}$

(b) $4.0 \times 10^{-5}\ \text{C}$

78. Integrated Concepts

A prankster applies $450\ \text{V}$ to an $80.0\ \mu\text{F}$ capacitor and then tosses it to an unsuspecting victim. The victim's finger is burned by the discharge of the capacitor through $0.200\ \text{g}$ of flesh. What is the temperature increase of the flesh? Is it reasonable to assume no phase change?

79. Unreasonable Results

(a) A certain parallel plate capacitor has plates of area $4.00\ \text{m}^2$, separated by $0.0100\ \text{mm}$ of nylon, and stores $0.170\ \text{C}$ of charge. What is the applied voltage?

(b) What is unreasonable about this result?

(c) Which assumptions are responsible or inconsistent?

Solution

(a) $14.2\ \text{kV}$

(b) The voltage is unreasonably large, more than 100 times the breakdown voltage of nylon.

(c) The assumed charge is unreasonably large and cannot be stored in a capacitor of these dimensions.

19.6: Capacitors in Series and Parallel

80. Find the total capacitance of the combination of capacitors in Figure 19.7.4.

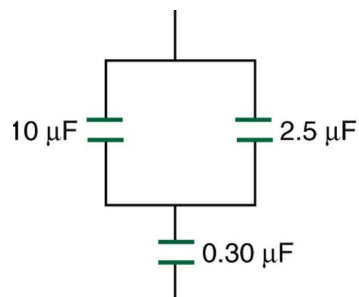


Figure 19.7.4: A combination of series and parallel connections of capacitors.

Solution

$0.293 \mu\text{F}$

81. Suppose you want a capacitor bank with a total capacitance of 0.750 F and you possess numerous 1.50 mF capacitors. What is the smallest number you could hook together to achieve your goal, and how would you connect them?

82. What total capacitances can you make by connecting a $5.00 \mu\text{F}$ and an $8.00 \mu\text{F}$ capacitor together?

Solution

$3.08 \mu\text{F}$ in series combination, $13.0 \mu\text{F}$ in parallel combination

83. Find the total capacitance of the combination of capacitors shown in Figure 19.7.5.

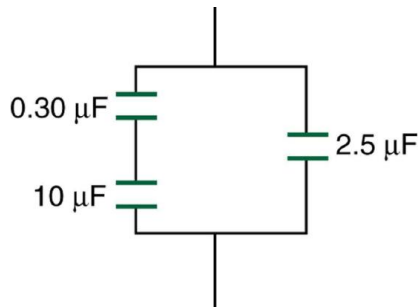


Figure 19.7.5: A combination of series and parallel connections of capacitors.

Solution

$2.79 \mu\text{F}$

84. Find the total capacitance of the combination of capacitors shown in Figure.

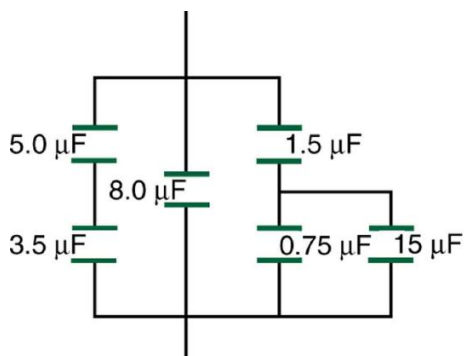


Figure 19.7.6: A combination of series and parallel connections of capacitors.

85. (a) An $8.00 \mu\text{F}$ capacitor is connected in parallel to another capacitor, producing a total capacitance of $5.00 \mu\text{F}$. What is the capacitance of the second capacitor?

(b) What is unreasonable about this result?

(c) Which assumptions are unreasonable or inconsistent?

Solution

(a) $-3.00 \mu\text{F}$

(b) You cannot have a negative value of capacitance.

(c) The assumption that the capacitors were hooked up in parallel, rather than in series, was incorrect. A parallel connection always produces a greater capacitance, while here a smaller capacitance was assumed. This could happen only if the capacitors are connected in series.

19.7: Energy Stored in Capacitors

86. (a) What is the energy stored in the $10.0 \mu\text{F}$ capacitor of a heart defibrillator charged to $9.00 \times 10^3 \text{ V}$?

(b) Find the amount of stored charge.

Solution

(a) 405 J

(b) 90.0 mC

87. In open heart surgery, a much smaller amount of energy will defibrillate the heart.

(a) What voltage is applied to the $8.00 \mu\text{F}$ capacitor of a heart defibrillator that stores 40.0 J of energy?

(b) Find the amount of stored charge.

Solution

(a) 3.16 kV

(b) 25.3 mC

88. A $165 \mu\text{F}$ capacitor is used in conjunction with a motor. How much energy is stored in it when 119 V is applied?

89. Suppose you have a 9.00 V battery, a $2.00 \mu\text{F}$ capacitor, and a $7.40 \mu\text{F}$ capacitor.

(a) Find the charge and energy stored if the capacitors are connected to the battery in series.

(b) Do the same for a parallel connection.

Solution

(a) $1.42 \times 10^{-5} \text{ C}$, $6.38 \times 10^{-5} \text{ J}$

(b) $8.46 \times 10^{-5} \text{ C}$, $3.81 \times 10^{-4} \text{ J}$

90. A nervous physicist worries that the two metal shelves of his wood frame bookcase might obtain a high voltage if charged by static electricity, perhaps produced by friction.

(a) What is the capacitance of the empty shelves if they have area $1.00 \times 10^2 \text{ m}^2$ and are 0.200 m apart?

(b) What is the voltage between them if opposite charges of magnitude 2.00 nC are placed on them?

(c) To show that this voltage poses a small hazard, calculate the energy stored.

Solution

(a) $4.43 \times 10^{-12} \text{ F}$

(b) 452 V

(c) $4.52 \times 10^{-7} \text{ J}$

91. Show that for a given dielectric material the maximum energy a parallel plate capacitor can store is directly proportional to the volume of dielectric ($\text{Volume} = A \cdot d$). Note that the applied voltage is limited by the dielectric strength.

92. Construct Your Own Problem

Consider a heart defibrillator similar to that discussed in [Example](#). Construct a problem in which you examine the charge stored in the capacitor of a defibrillator as a function of stored energy. Among the things to be considered are the applied voltage and whether it should vary with energy to be delivered, the range of energies involved, and the capacitance of the defibrillator. You may also wish to consider the much smaller energy needed for defibrillation during open-heart surgery as a variation on this problem.

93. (a) On a particular day, it takes $9.60 \times 10^3 \text{ J}$ of electric energy to start a truck's engine. Calculate the capacitance of a capacitor that could store that amount of energy at 12.0 V.

- (b) What is unreasonable about this result?
- (c) Which assumptions are responsible?

Solution

- (a) 133 F
- (b) Such a capacitor would be too large to carry with a truck. The size of the capacitor would be enormous.
- (c) It is unreasonable to assume that a capacitor can store the amount of energy needed.

Contributors and Attributions

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