# CHAPTER 14 Review

## REFLECTING ON CHAPTER 14

- The magnitudes of the gravitational force and the Coulomb force both follow inverse square laws.
$$F_g = G\frac{m_1 m_2}{r^2} \qquad F_Q = k\frac{q_1 q_2}{r^2}$$
- The equations for gravitational force and Coulomb force were developed for point masses and point charges. However, if the masses or charges are perfect spheres, the laws apply at any point outside of the spheres.
- Since magnetic monopoles do not exist or have never been detected, magnetic forces cannot be described in the same form as gravitational and electrostatic forces. However, they appear to follow an inverse square relationship.
- Because charges, masses, and magnets do not have to be in contact to exert forces on each other, early physicists classified their interactions as action-at-a-distance forces.
- Michael Faraday developed the concept of a field in which masses, charges, and magnets influence the space around themselves in the form of a field. When a second mass, charge, or magnet is placed in the field created by the first, the field exerts a force on the object.
- The strength of an electric field at a point $P$ is described as the electric field intensity and is mathematically expressed as "force per unit charge," $\vec{E} = \frac{\vec{F}_Q}{q_t}$.
- The direction of an electric field at any point is the direction that a *positive* charge would move if it was placed at that point.
- The strength of a gravitational field at any point $P$ is called the gravitational field intensity and is mathematically expressed as "force per unit mass," $\vec{g} = \frac{\vec{F}_g}{m_t}$.
- The direction of a gravitational field is always toward the centre of the mass creating the field.
- For the special case of a point charge $q$ creating the field, the magnitude of the electric field intensity at a point $P$, a distance $r$ from the charge, is given by $|\vec{E}| = k\frac{q}{r^2}$.
- For the special case of a point mass $m$ creating the field, the magnitude of the gravitational field intensity at a point $P$, a distance $r$ from the mass, is given by $|\vec{g}| = G\frac{m}{r^2}$.
- To find the electric field intensity in the vicinity of several point charges, find the field intensity due to each charge alone and then add them vectorially.
- Field lines are used to describe a field over a large area or volume. Field lines are drawn so that the intensity of the field is proportional to the density of the lines. The direction of a field at any point is the tangent to the field line at that point.
- A charge placed in an electric field or a mass in a gravitational field has potential energy.
- Potential energy of any type is not absolute, but relative to an arbitrary reference position or condition. The reference position for gravitational or electric potential energy in a field created by a point source is often chosen to be at an infinite distance from the point source.
- The electric potential energy of two point charges a distance $r$ apart is given by
$$E_Q = k\frac{q_1 q_2}{r}$$
- The gravitational potential energy of two masses a distance $r$ apart is given by
$$E_g = -G\frac{m_1 m_2}{r}$$
- Electric potential difference is defined as the potential energy per unit charge and is expressed mathematically as $V = \frac{E_Q}{q}$.
- For the special case of the electric potential difference in an electric field created by a point charge $q$, the electric potential difference is $V = k\frac{q}{r}$. This is the potential difference between a point a distance $r$ from charge $q$ and another point an infinite distance from charge $q$.

- Since work must be done on a charge to give it potential energy, the change in the potential between two points is the amount of work done on a unit charge that was moved between those two points, or $\Delta V = \frac{W}{q}$.
- In any field, there will be many points that have the same potential. When all of the points that are at the same potential are connected, an equipotential surface is formed.
- No work is done when a charge or mass moves over an equipotential surface.

## Knowledge/Understanding

1. In your own words, define
   (a) electric charge
   (b) Coulomb's law
   (c) field
2. The field of an unknown charge is first mapped with a $1.0 \times 10^{-8}$ C test charge, then repeated with a $2.0 \times 10^{-8}$ C test charge.
   (a) Would the same forces be measured with the two test charges? Explain your answer.
   (b) Would the same fields be determined using the two test charges? Explain your answer.
3. Both positive and negative charges produce electric fields. Which direction, toward or away from the charge, does the field point for each charge?
4. What is the difference between electric field intensity, electric potential difference, and electric potential energy?
5. What determines the magnitude and direction of an electric field at a particular point a distance from a source charge?
6. Is electric field strength a scalar quantity or a vector quantity? Is electric potential difference a scalar or vector quantity?
7. If the gravitational potential energy for an object at height $h$ above the ground is given by $mg\Delta h$, what is the gravitational potential difference (similar in nature to the electric potential difference) between the two levels? What are the units of gravitational potential difference?
8. Units of electric field strength can be given in N/C or volts per metre, V/m. Show that these units are equivalent.

## Inquiry

9. Consider a charge of +2.0 $\mu$C placed at the origin of an $x$–$y$-coordinate system and a charge of –4.0 $\mu$C placed 40.0 cm to the right. Where must a third charge be placed — between the charges, to the left of the origin, or beyond the second charge — to experience a net force of zero? Argue your case qualitatively without working out a solution. Consider both positive and negative charges.
10. (a) In a room, gravity exerts a downward pull on a ball held by a string. Sketch the gravitational field in the room.
    (b) Suppose a room has a floor that is uniformly charged and positive and a ceiling that carries an equal amount of negative charge. Neglecting gravity, how will a small, positively charged sphere held by a string behave? Sketch the electric field in the room.
    (c) Comment on any similarities and differences between the above situations.

## Communication

11. (a) Sketch the electric field lines for a positive charge and a negative charge that are very far apart.
    (b) Show how the field lines change if the two charges are then brought close together.
12. Sketch the field lines for two point charges, 2Q and –Q, that are close together.
13. Explain why electric field lines never cross.
14. What is the gravitational field intensity at the centre of Earth?

## Making Connections

**15.** Develop a feeling for the unit of the coulomb by examining some everyday situations. How much charge do you discharge by touching a doorknob after walking on a wool rug? How much charge does a comb accumulate when combing dry hair? How much charge does a lightning bolt discharge? What is the smallest charge that can be measured in the laboratory? The largest charge?

**16.** Make a list of the magnitudes of some electric fields found in everyday life, such as in household electric wiring, in radio waves, in the atmosphere, in sunlight, in a lightning bolt, and so on. Where can you find the weakest and greatest electric fields?

**17.** In November 2001, NASA launched the Gravity Recovery and Climate Experiment, or GRACE, involving a pair of satellites designed to monitor tiny variations in Earth's gravitational field. The two satellites follow the same orbit, one 220 km ahead of the other. As both satellites are in free fall, regions of slightly stronger gravity will affect the lead satellite first. By accurately measuring the changes in the distance between the satellites with microwaves, GRACE will be able to detect minute fluctuations in the gravitational field. Research the goals and preliminary findings of GRACE. In particular, examine how both ocean studies and meteorological studies will benefit from GRACE.

## Problems for Understanding

**18.** What is the force of repulsion between two equal charges, each of 1 C, that are separated by a distance of 1 km?

**19.** Calculate the force between two free electrons separated by 0.10 nm.

**20.** The force of attraction between two charged Ping-Pong™ balls is $2.8 \times 10^{-4}$ N. If the charges are +8.0 nC and –12.0 nC, how far apart are their centres?

**21.** Three point charges, A (+2.0 $\mu$C), B (+4.0 $\mu$C), and C (–6.0 $\mu$C), sit consecutively in a line. If A and B are separated by 1.0 m and B and C are separated by 1.0 m, what is the net force on each charge?

**22.** Three charges sit on the vertices of an equilateral triangle, the sides of which are 30.0 cm long. If the charges are A = +4.0 $\mu$C, B = +5.0 $\mu$C and C = +6.0 $\mu$C (clockwise from the top vertex), find the force on each charge.

**23.** In the Bohr model of the hydrogen atom, an electron orbits a proton at a radius of approximately $5.3 \times 10^{-11}$ m. Compare the gravitational and the electrostatic forces between the proton and the electron.

**24.** Suppose the attractive force between Earth and the Moon, keeping the Moon in its orbit, was not gravitational but was, in fact, a Coulombic attraction. Predict the magnitude of the possible charges on Earth and the Moon that would cause an identical force of attraction.

**25.** What is the ratio of the electric force to the gravitational force between two electrons?

**26.** Calculate the charge (sign and magnitude) on a 0.30 g pith ball if it is supported in space by a downward field of $5.2 \times 10^{-5}$ N/C.

**27.** A 3.0 g Ping Pong™ ball is suspended from a thread 35 cm long. When a comb is brought to the same height, the Ping Pong™ ball is repelled and the thread makes an angle of 10.0˚ with the vertical. What is the electric force exerted on the Ping Pong™ ball?

**28.** The gravitational field intensity at a height of 150 km ($1.50 \times 10^2$ km) above the surface of Uranus is 8.71 N/kg. The radius of Uranus is $2.56 \times 10^7$ m.

**(a)** Calculate the mass of Uranus.

**(b)** Calculate the gravitational field intensity at the surface of Uranus.

**(c)** How much would a 100 kg ($1.00 \times 10^2$ kg) person weigh on the surface of Uranus?

**29.** If a planet, P, has twice the mass of Earth and three times the radius of Earth, how would the gravitational field intensity at its surface compare to that of Earth?

30. The Bohr model of the hydrogen atom consists of an electron ($q_e = -e$) travelling in a circular orbit of radius $5.29 \times 10^{-11}$ m around a proton ($q_p = +e$). The attraction between the two gives the electron the centripetal force required to stay in orbit. Calculate the
(a) force between the two particles
(b) speed of the electron
(c) electric field the electron experiences
(d) electric potential difference the electron experiences

31. What mass should an electron have if the gravitational and electric forces between two electrons were equal in magnitude? How many times greater than the accepted value of the electron mass is this?

32. A charge, $q_1 = +4$ nC, experiences a force of $3 \times 10^{-5}$ N to the east when placed in an electric field. If the charge is replaced by another, $q_2 = -12$ nC, what will be the magnitude and direction of the force on the charge at that position?

33. If the electric potential energy between two charges of 1.5 $\mu$C and 6.0 $\mu$C is 0.16 J, what is their separation?

34. Two electric charges are located on a coordinate system as follows: $q_1 = +35$ $\mu$C at the origin (0,0) and $q_2 = -25$ $\mu$C at the point (3,0), where the coordinates are in units of metres. What is the electric field at the point (1,2)?

35. (a) What is the change in electric potential energy of a charge of −15 nC that moves in an electric field from an equipotential surface of +4 V to an equipotential surface of +9 V?
(b) Does the charge gain energy or lose energy?

36. To move a charge of +180 nC from a position where the electric potential difference is +24 V to another position where the potential difference is +8 V, how much work must be done?

37. A spherical Van de Graaff generator terminal (capable of building up a high voltage) has a radius of 15 cm.
(a) Calculate the potential at the surface if the total charge on the terminal is 75 nC.
(b) If you touch the generator with a hollow steel ball of radius 6.5 cm, are the spheres "equipotential" while in contact?
(c) Calculate the charge on each sphere when they are separated.

38. Two identical charges, $q_1 = q_2 = 6.0$ $\mu$C, are separated by 1.0 m.
(a) Calculate the electric field and electric potential difference at point P, midway between them.
(b) Replace one of the charges with a charge of the same magnitude but opposite sign and repeat the calculation in (a).
(c) Discuss your solutions.

39. Points X and Y are 30.0 mm and 58 mm away from a charge of +8.0 $\mu$C.
(a) How much work must be done in moving a +2.0 $\mu$C charge from point Y to point X?
(b) What is the potential difference between points X and Y?
(c) Which point is at the higher potential?

40. Points R and S are 5.9 cm and 9.6 cm away from a charge of +6.8 $\mu$C.
(a) What is the potential difference between the points R and S?
(b) Which point is at the higher potential?