Chapter 14

Fields and Forces

Practice Problem Solutions

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1. **Conceptualize the Problem**
   - *Force, charge* and *distance* are related by *Coulomb's law.*

   Identify the Goal
   The electrostatic force, F, between the given charges

   Identify the Variables

Known	Implied	Unknown
$q_1 = -2.4\ \mu\text{C}$	$k = 9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}$	F
$q_2 = +5.3\ \mu\text{C}$		
$r = 58\ \text{cm}$		

   Develop a Strategy
   Coulomb's law can be applied to find the magnitude of the force.

   Calculations

$$F = k\frac{q_1 q_2}{r^2}$$

$$F = \left(9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(2.4 \times 10^{-6}\ \text{C})(5.3 \times 10^{-6}\ \text{C})}{\left(58\ \text{cm} \times \frac{1.00\ \text{m}}{100\ \text{cm}}\right)^2}$$

$$F = 0.3403\ \text{N}$$

$$F \cong 0.34\ \text{N}$$

   The electrostatic force between the charges is about 0.34 N.

   Validate the Solution
   Charges in the microcoulomb range are expected to exert moderate forces on each other, so this result is reasonable.

2. Solution is similar to Practice Problem 1.
   The separation of the charges is about 0.80 m.

3. Solution is similar to Practice Problem 1.
   The magnitude of each charge is about 5.1×10^{-7} C.

4. Solution is similar to Practice Problem 1.
   The force decreases by a factor of $4^2 = 16$, to 0.50 N (attractive).

5. Solution is similar to Practice Problem 1.
   After touching the objects together and increasing their separation to $2d$, the force between them will be about 0.17 N.

Practice Problem Solutions

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6. **Conceptualize the Problem**
   - *Force*, *charge* and *distance* are related by *Coulomb's law.*

- The same (Coulomb) force that repels the two protons must support the weight of the second proton.
- The second proton must be placed above the first if its weight is to be supported by the repulsive force between the two protons.

Identify the Goal

The distance between the protons, r, if the weight of the second proton is supported by their mutual repulsive force

Identify the Variables

Known	Implied	Unknown
$q_1 = 1.6 \times 10^{-19}$ C	$k = 9.0 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}$	r
$q_2 = 1.6 \times 10^{-19}$ C	$g = 9.81$ m/s^2	
	$m = 1.67 \times 10^{-27}$ kg	

Develop a Strategy

Write down the equation that shows the Coulomb force is the same as the weight of the proton.

Calculations

$$F = k\frac{q_1 q_2}{r^2} = mg$$

$$r^2 = \frac{kq_1q_2}{mg}$$

$$r = \sqrt{\frac{kq_1q_2}{mg}}$$

$$r = \sqrt{\frac{\left(9.0 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.6 \times 10^{-19}\ \text{C})^2}{(1.67 \times 10^{-27}\ \text{kg})(9.81\ \text{m/s}^2)}}$$

$$r = 0.1186\ \text{m}$$

$$r \cong 0.12\ \text{m}$$

The second proton should be placed about 0.12 m directly above the force so that the force of repulsion supports its weight.

Validate the Solution

Check the units:

$$\left(\frac{\left(\frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(\text{C}^2)}{(\text{kg})(\text{m/s}^2)}\right)^{\frac{1}{2}} = \left(\frac{\text{N}\cdot\text{m}^2}{(\text{kg})(\text{m/s}^2)}\right)^{\frac{1}{2}} = \left(\frac{\text{N}\cdot\text{m}^2}{\text{N}}\right)^{\frac{1}{2}} = \left(\text{m}^2\right)^{\frac{1}{2}} = \text{m},\ \text{as required.}$$

7. Solution is similar to Practice Problem 1.

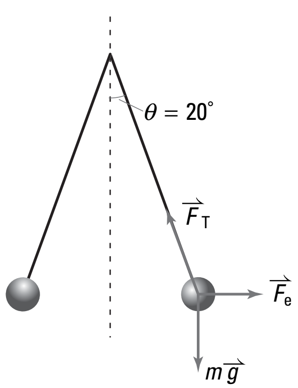
The force on charge A is 1.2×10^{-2} N[W73S].

The force on charge B is 1.6×10^{-2} N[E63N].

The force on charge C is 4.6×10^{-3} N[W36S].

8. Solution is similar to Practice Problem 1.

The net electrostatic force on q_1 is 8.7 N[E18°N]



9. Conceptualize the Problem

- Draw a *free-body diagram* that shows all the forces that the suspended pith ball experiences: the tension in the string, the electrostatic force from the second pith ball and the force of gravity.
- The suspended ball experiences no net acceleration in either the x- or y-directions.
- Newton's second law can be applied in each the x- and y-directions.
- *Coulomb's law* relates *electrostatic force, charge* and *distance* and can be used with the known variables in the problem to find the unknown charge.

Identify the Goal
The charge, q, on each of the pith balls

Identify the Variables

Known	Implied	Unknown
$m = 1.5$ g	$k = 9.0 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}$	q
$r = 2.6$ cm	$g = 9.81 \text{ m/s}^2$	F_T
$\theta = 20°$		

Develop a Strategy
Apply Newton's second law in the x- and y-direction.

Calculations

x:

$$F_e + (-F_T \sin\theta) = 0$$
$$F_e = F_T \sin\theta$$

y:

$$mg + (-F_T \cos\theta) = 0$$
$$F_T = \frac{mg}{\cos\theta}$$

Substitute the second (y) equation into the first (x).

$$F_e = F_T \sin\theta$$
$$F_e = \left(\frac{mg}{\cos\theta}\right)\sin\theta$$
$$F_e = mg\tan\theta$$

Expand the term for the electrostatic force and solve for the charge.

$$F_e = \frac{kq^2}{r^2} = mg\tan\theta$$
$$q^2 = \frac{mgr^2\tan\theta}{k}$$
$$q = \sqrt{\frac{mgr^2\tan\theta}{k}}$$
$$q = \pm\sqrt{\frac{1.5\text{ g} \times \frac{1\text{ kg}}{1000\text{ g}}(9.81\text{ m/s}^2)\left(2.6\text{ cm} \times \frac{1.00\text{ m}}{100\text{ cm}}\right)^2 \tan 20°}{9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}}}$$
$$q = \pm 2.006 \times 10^{-8}\text{ C}$$
$$q \cong \pm 2.0 \times 10^{-8}\text{ C}$$

The charge on the pith balls will be 2.0×10^{-8} C and each charge will have the same sign.

Validate the Solution

Check the units: $\sqrt{\dfrac{\text{kg}(\text{m/s}^2)(\text{m}^2)}{\frac{\text{N}\cdot\text{m}^2}{\text{C}^2}}} = \text{C}$

10. Solution is similar to Practice Problem 9.
The charge on the pith balls will be 7.9×10^{-8} C and each charge will have the same sign.

Practice Problem Solutions

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11. Conceptualize the Problem
- The electric field intensity is related to the force and charge.

Identify the Goal
The magnitude and direction of the electric field, $\vec{E}$, at the location of the charge

Identify the Variables

Known	Implied	Unknown
$q = 3.2 \times 10^{-5}$ C $F = 4.8$ N[right]	$k = 9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}$	$\vec{E}$

Develop a Strategy

Find the electric field intensity by using the equation that defines electric field.

Calculations

$$\vec{E} = \frac{\vec{F}}{q}$$

$$\vec{E} = \frac{4.8\ \text{N[right]}}{3.2 \times 10^{-5}\ \text{C}}$$

$$\vec{E} = 1.5 \times 10^5\ \text{N/C[right]}$$

The electric field is 1.5×10^5 N/C[to the right]

Validate the Solution

The electric field has units of N/C, as expected. Its direction is the same as the force on the positive charge.

12. Solution is similar to Practice Problem 11.
The force on the charge will be 0.019 N[W].

13. Solution is similar to Practice Problem 11.
The electric field is 2.5×10^4 N/C[to the left].

14. Solution is similar to Practice Problem 11.
The charge is -4.0×10^{-4} C.

Practice Problem Solutions

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15. Conceptualize the Problem

- The definition of gravitational field intensity is the gravitational force per unit mass.

Identify the Goal

The gravitational field intensity, $\vec{g}$, at the surface of Mars

Identify the Variables

Known	Implied	Unknown
$\vec{F} = 7.5$ N[down] $m = 2.0$ kg	Note that [down] means [toward the planet's centre].	$\vec{g}$

Develop a Strategy

Find the gravitational field intensity by using the equation for field intensity and the given variables.

Calculations

$$\vec{g} = \frac{\vec{F}}{m}$$

$$\vec{g} = \frac{7.5\ \text{N[down]}}{2.0\ \text{kg}}$$

$$\vec{g} = 3.75\ \text{N/kg[down]}$$

$$\vec{g} \cong 3.8\ \text{N/kg[down]}$$

The gravitational field intensity at the surface of Mars is 3.8 N/kg[down].

Validate the Solution
Mars is known to have a lower mass than Earth, so it is expected to have a lower gravitational field intensity too.

16. Solution is similar to Practice Problem 15.
The gravitational force on the object would be 52 N[down].

17. Solution is similar to Practice Problem 15.
The object's mass is 3.46 kg.

18. Solution is similar to Practice Problem 15.
The gravitational field intensity would be 2.60 N/kg[down].

19. Solution is similar to Practice Problem 15.
The centripetal acceleration is 2.60 m/s^2[toward centre].

Practice Problem Solutions

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20. Conceptualize the Problem
- At any point outside of a charged sphere, the *electric field* is the same as it would be if the charge was concentrated at a point at the centre of the sphere.
- The *electric field* is related to the *source charge* and *distance*.
- The *direction* of the field is the direction in which a positive charge would move if it was placed at that point in the field. That is, the direction is radially outward from positive charges and toward negative charges.

Identify the Goal
The electric field intensity, $\vec{E}$

Identify the Variables

Known	Implied	Unknown
$q = -2.8\ \mu C$	$k = 9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}$	$\vec{E}$
$r = 18.0$ cm		

Develop a Strategy
Find the field intensity by using the equation for the special case of the field near a point charge.

Calculations

$$\vec{E} = k\frac{q}{r^2}$$

$$\vec{E} = \left(9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}\right)\frac{(-2.8 \times 10^{-6}\ C)}{\left(18.0\ cm \times \frac{1.00\ m}{100\ cm}\right)^2}$$

$$\vec{E} = -7.7778 \times 10^5\ N/C$$

$$\vec{E} \cong -7.8 \times 10^5\ N/C$$

The electric field intensity at the given distance from the sphere is -7.8×10^5 N/C, and the negative sign indicates it is directed toward the sphere.

Validate the Solution
Check the units: $\frac{N \cdot m^2}{C^2}\frac{C}{m^2} = \frac{N}{C}$, as required.

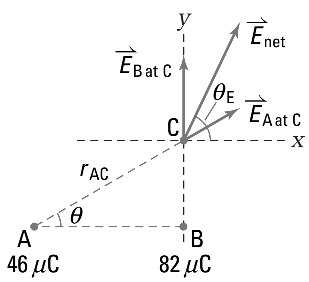
21. Solution is similar to Practice Problem 20.
The sign and magnitude of the charge is -1.2×10^{-5} C.

22. Solution is similar to Practice Problem 20.
The point P is about 0.32 m from the centre of the charge.

23. Solution is similar to Practice Problem 20.
The number of electrons that should be removed is about 5.80×10^9.

24. Solution is similar to Practice Problem 20.
The electric field intensity is -1.5×10^6 N/C, directed toward the sphere.

25. Solution is similar to Practice Problem 20.
The point M is about 0.080 m from the centre of the charge.



26. Conceptualize the Problem

- Since force vectors must be added vectorially and field vectors are force vectors divided by the unit charge, the field vectors must also be added vectorially.
- The magnitude of the field vectors can be determined individually.
- Draw a vector diagram showing the field intensity vectors at point C and then superimpose an *x-y* coordinate system on the drawing, with the origin at point C.

Identify the Goal

The electric field intensity, $\vec{E}$, at point C

Identify the Variables

Known	Implied	Unknown
$q_A = 46\ \mu C$	$k = 9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}$	$\vec{E}$
$q_B = 82\ \mu C$		θ (at point A)
$r_{AB} = 5.0$ cm		θ_E
$r_{BC} = 4.0$ cm		

Develop a Strategy / **Calculations**

Calculate the distance between points A and C by using the Pythagorean theorem.

$$r_{AC}^2 = r_{AB}^2 + r_{BC}^2$$
$$r_{AC}^2 = (5.0\text{ cm})^2 + (4.0\text{ cm})^2$$
$$r_{AC} = \sqrt{41\text{ cm}^2}$$
$$r_{AC} = 6.403\text{ cm}$$

Calculate the electric field intensity of both of the charges at point C, using the equation for the special case of the field intensity near a point charge.

$$|\vec{E}| = k\frac{q}{r^2}$$
$$|\vec{E}_{A\,at\,C}| = \left(9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}\right)\frac{(46 \times 10^{-6}\text{ C})}{\left(6.403\text{ cm} \times \frac{1.00\text{ m}}{100\text{ cm}}\right)^2}$$
$$|\vec{E}_{A\,at\,C}| = 1.00976 \times 10^8\text{ N/C}$$
$$|\vec{E}_{B\,at\,C}| = \left(9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}\right)\frac{(82 \times 10^{-6}\text{ C})}{\left(4.0\text{ cm} \times \frac{1.00\text{ m}}{100\text{ cm}}\right)^2}$$
$$|\vec{E}_{B\,at\,C}| = 4.612 \times 10^8\text{ N/C}$$

Find the angle at A between points B and C.

$$\tan\theta = \frac{\overline{BC}}{\overline{AB}}$$
$$\theta = \tan^{-1}\frac{\overline{BC}}{\overline{AB}}$$
$$\theta = \tan^{-1}\frac{4.0\text{ cm}}{5.0\text{ cm}}$$
$$\theta = 38.66°$$

Use the method of components to find the resultant electric field vector.

x-components:

$$E_{(A\,at\,C)x} = (1.00976 \times 10^8\text{ N/C})\cos 38.66°$$
$$E_{(A\,at\,C)x} = 7.8849 \times 10^7\text{ N/C}$$
$$E_{(B\,at\,C)x} = 0$$
$$E_{(net)x} = 7.8849 \times 10^7\text{ N/C}$$

y-components:

$E_{(\text{A at C})y} = (1.00976 \times 10^8\ \text{N/C}) \sin 38.66°$

$E_{(\text{A at C})y} = 6.3079 \times 10^7\ \text{N/C}$

$E_{(\text{B at C})y} = 4.612 \times 10^8\ \text{N/C}$

$E_{(\text{net})y} = 5.241 \times 10^8\ \text{N/C}$

Use the Pythagorean theorem to find the magnitude of the resultant vector.

$$|\vec{E}_{\text{net}}|^2 = |\vec{E}_{(\text{net})x}|^2 + |\vec{E}_{(\text{net})y}|^2$$
$$|\vec{E}_{\text{net}}|^2 = (7.8849 \times 10^7\ \text{N/C})^2 + (5.241 \times 10^8\ \text{N/C})^2$$
$$|\vec{E}_{\text{net}}|^2 = 2.809 \times 10^{17}\ (\text{N/C})^2$$
$$|\vec{E}_{\text{net}}| = 5.30 \times 10^8\ \text{N/C}$$

Use the definition of the tangent function to find the direction of the electric field vector at point C.

$$\tan \theta_{\text{E}} = \frac{E_{(\text{net})y}}{E_{(\text{net})x}}$$
$$\theta_{\text{E}} = \tan^{-1} \frac{5.241 \times 10^8\ \text{N/C}}{7.8849 \times 10^7\ \text{N/C}}$$
$$\theta_{\text{E}} = 81.4°$$

The electric field intensity at point C is 5.3×10^8 N/C[81.4° above the +x-axis].

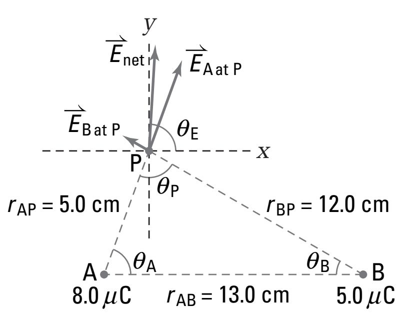
Validate the Solution

Charge B is larger than charge A and closer than charge A to point C, so it contributes more to the electric field intensity. Based on the magnitude of the electric field intensity due to charge B, the final result seems reasonable.

27. Solution is similar to Practice Problem 26.
The electric field intensity at point C is 1.9×10^4 N/C[86.7° above the +x-axis].

28. Solution is similar to Practice Problem 26.
The electric field intensity at point D is 3.4×10^6 N/C[23.7° above the −x-axis].

29. Solution is similar to Practice Problem 20.
The electric field intensity at a point midway between the charges is 2.25×10^{14} N/C[towards the negative charge], or -2.25×10^{14} N/C.



30. **Conceptualize the Problem**

- Since force vectors must be added vectorially and field vectors are force vectors divided by the unit charge, the field vectors must also be added vectorially.
- The magnitude of the field vectors can be determined individually.
- Draw a vector diagram showing the field intensity vectors at point P and then superimpose an x-y coordinate system on the drawing, with the origin at point P. This means that angles are measured from the positive x-axis.

Identify the Goal

The electric field intensity, $\vec{E}$, at point P

Identify the Variables

Known	Implied	Unknown
$q_{\text{A}} = 8.0\ \mu\text{C}$	$k = 9.0 \times 10^9\ \frac{\text{N·m}^2}{\text{C}^2}$	$\vec{E}$
$q_{\text{B}} = 5.0\ \mu\text{C}$		θ_{E} (the electric field direction)
$r_{\text{AP}} = 5.0$ cm		θ_{P} (at point P)
$r_{\text{BP}} = 12.0$ cm		θ_{A}
$r_{\text{AB}} = 13.0$ cm		θ_{B}

Develop a Strategy

Determine the geometry of the triangle: calculate the individual angles.

Note that because

$r_{AP}^2 + r_{BP}^2 = (5.0\text{ cm})^2 + (12.0\text{ cm})^2 = r_{AB}^2$

or, $r_{AB} = \sqrt{169\text{ cm}^2} = 13.0\text{ cm}$

the triangle is a right triangle and the angle between sides $\overline{AP}$ and $\overline{BP}$ (i.e. at point P) is 90°.

If the above is not immediately noticed, the same result can be obtained from the cosine law: $c^2 = a^2 + b^2 - 2ab\cos\theta$

Calculations

$$r_{AB}^2 = r_{AP}^2 + r_{BP}^2 - 2r_{AP}r_{BP}\cos\theta_P$$

$$\theta_P = \cos^{-1}\left(\frac{r_{AB}^2 - r_{AP}^2 - r_{BP}^2}{-2r_{AP}r_{BP}}\right)$$

$$\theta_P = \cos^{-1}\left(\frac{(13.0\text{ cm})^2 - (5.0\text{ cm})^2 - (12.0\text{ cm})^2}{-2(5.0\text{ cm})(12.0\text{ cm})}\right)$$

$$\theta_P = 90°$$

Determine the angles of the other two sides from trigonometry.

$$\cos\theta_A = \frac{r_{AP}}{r_{AB}}$$

$$\theta_A = \cos^{-1}\left(\frac{5.0\text{ cm}}{13.0\text{ cm}}\right)$$

$$\theta_A = 67.38°$$

$$\cos\theta_B = \frac{r_{BP}}{r_{AB}}$$

$$\theta_B = \cos^{-1}\left(\frac{12.0\text{ cm}}{13.0\text{ cm}}\right)$$

$$\theta_B = 22.62°$$

Calculate the electric field intensity of both of the charges at point P, using the equation for the special case of the field intensity near a point charge.

Use the method of components to find the resultant electric field vector.

$$E = k\frac{q}{r^2}$$

x-components:

$$E_x = k\frac{q}{r^2}\cos\theta$$

$$E_{(\text{A at P})x} = \left(9.0\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(8.0\times10^{-6}\text{ C})}{\left(5.0\text{ cm}\times\frac{1.00\text{ m}}{100\text{ cm}}\right)^2}\cos 67.38°$$

$$E_{(\text{A at P})x} = 1.108\times10^7\text{ N/C}$$

$$E_{(\text{B at P})x} = \left(9.0\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(5.0\times10^{-6}\text{ C})}{\left(12.0\text{ cm}\times\frac{1.00\text{ m}}{100\text{ cm}}\right)^2}\cos(180° - 22.62°)$$

$$E_{(\text{B at P})x} = -2.885\times10^6\text{ N/C}$$

$$E_{(\text{net})x} = 8.195\times10^6\text{ N/C}$$

y-components:

$$E_y = k\frac{q}{r^2}\sin\theta$$

$$E_{(\text{A at P})y} = \left(9.0\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(8.0\times10^{-6}\text{ C})}{\left(5.0\text{ cm}\times\frac{1.00\text{ m}}{100\text{ cm}}\right)^2}\sin 67.38°$$

$$E_{(\text{A at P})y} = 2.658\times10^7\text{ N/C}$$

$$E_{(\text{B at P})y} = \left(9.0\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(5.0\times10^{-6}\text{ C})}{\left(12.0\text{ cm}\times\frac{1.00\text{ m}}{100\text{ cm}}\right)^2}\sin(180° - 22.62°)$$

$$E_{(\text{B at P})y} = 1.202\times10^6\text{ N/C}$$

$$E_{(\text{net})y} = 2.778\times10^7\text{ N/C}$$

Use the Pythagorean theorem to find the magnitude of the resultant vector.

$$|\vec{E}_{\text{net}}|^2 = |\vec{E}_{(\text{net})x}|^2 + |\vec{E}_{(\text{net})y}|^2$$

$$|\vec{E}_{\text{net}}|^2 = (8.195\times10^6\text{ N/C})^2 + (2.778\times10^7\text{ N/C})^2$$

$$|\vec{E}_{\text{net}}|^2 = 8.3889\times10^{14}\ (\text{N/C})^2$$

$$|\vec{E}_{\text{net}}| = 2.896\times10^7\text{ N/C}$$

$$|\vec{E}_{\text{net}}| \cong 2.9\times10^7\text{ N/C}$$

Use the definition of the tangent function to find the direction of the electric field vector at point P.

$$\tan\theta_E = \frac{E_{(\text{net})y}}{E_{(\text{net})x}}$$

$$\theta_E = \tan^{-1}\frac{2.778\times10^7\text{ N/C}}{8.195\times10^6\text{ N/C}}$$

$$\theta_E = 73.6°$$

The electric field intensity at point P is 2.9×10^7 N/C[73.6° above the +*x*-axis].

Validate the Solution
Both the x- and y-components of the resultant electric field vector are positive, so the direction of the electric field should be between 0° and 90° above the x-axis. Charge A is closer to point P than charge B, and it has a greater magnitude, so it should contribute more to the electric field intensity at point P than charge B, and it does.

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31. Conceptualize the Problem
- Since the point in question is outside the surface of Earth, the gravitational field there is the same as it would be if Earth's mass was concentrated at a point at Earth's centre. Therefore, the equation for the gravitational field intensity near a point mass applies.

Identify the Goal
The gravitational field intensity, $\vec{g}$, at a point beyond Earth's surface

Identify the Variables

Known	Implied	Unknown
$r = 8.4 \times 10^7$ m	$G = 6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}$	$\vec{g}$
$M_E = 5.98 \times 10^{24}$ kg		

Develop a Strategy
Use the equation for the gravitational field intensity near a point source.
The gravitational field intensity at this distance above Earth's surface is about 5.7×10^{-2} N/kg, directed toward Earth's centre.

Calculations

$$\vec{g} = G\frac{M_E}{r^2}[\text{toward centre}]$$
$$\vec{g} = \left(6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}\right)\frac{5.98 \times 10^{24}\text{ kg}}{(8.4 \times 10^7\text{ m})^2}[\text{toward centre}]$$
$$\vec{g} = 5.653 \times 10^{-2}\text{ N/kg}[\text{toward centre}]$$
$$\vec{g} \cong 5.7 \times 10^{-2}\text{ N/kg}[\text{toward centre}]$$

Validate the Solution
The distance from Earth's centre is about 13.2 times greater than the radius of Earth; therefore, it is expected that the gravitational field intensity at this point will be roughly $13.2^2 = 173.3$ times lower than at the surface. Calculations show good agreement: (9.81 N/kg)/173.3 = 0.0565 N/kg.

32. Solution is similar to Practice Problem 31.
The radius of Saturn is about 3.81×10^7 m.

33. Solution is similar to Practice Problem 31.
The acceleration due to gravity on the surface of Venus is about 8.09 N/kg[toward centre].

34. Conceptualize the Problem
- The data about the falling object can be used with the appropriate *kinematics* equation to find the *acceleration due to gravity*.
- The *acceleration due to gravity* is the same as the *gravitational field intensity*.
- The *gravitational field intensity* relates the *gravitational mass* and the *radius*.

Identify the Goal
The mass, M, of the planet

Identify the Variables

Known	Implied	Unknown
$m = 3.60\text{ kg}$	$G = 6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}$	$\vec{g}$
$t = 2.60\text{ s}$	$v_1 = 0\text{ m/s}$	M
$\Delta y = 1.86\text{ m}$		
$r = 8.40 \times 10^6\text{ m}$		

Develop a Strategy

Use a kinematics equation that relates vertical displacement to acceleration, time and initial velocity.
Rearrange to find the acceleration due to gravity.

Calculations

$$\Delta y = v_1 t + \frac{1}{2}at^2$$
$$\Delta y = 0 + \frac{1}{2}at^2$$
$$a = \frac{2\Delta y}{t^2}$$
$$a = \frac{2(1.86\text{ m})}{(2.60\text{ s})^2}$$
$$a = 0.550\text{ m/s}^2$$

Use the equation for the magnitude of the gravitational field intensity near a point source.
Rearrange to find the mass.
Note that the acceleration calculated above is equal to the gravitational field intensity, $a = g$.

$$g = G\frac{M}{r^2}$$
$$M = \frac{r^2 g}{G}$$
$$M = \frac{(8.40 \times 10^6\text{ m})^2(0.550\text{ m/s}^2)}{6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}}$$
$$M = 5.8183 \times 10^{23}\text{ kg}$$
$$M \cong 5.82 \times 10^{23}\text{ kg}$$

The mass of the planet is 5.82×10^{23} kg.

Validate the Solution

The gravitational field intensity is more than ten times smaller than that of Earth and the radii of the planet and Earth are similar, so it is expected that the mass of the planet will be smaller than Earth's by about a factor of ten, and it is.

35. Solution is similar to Practice Problem 31.
The gravitational field intensity is 5.0×10^{-11} N/kg[toward centre].

36. Solution is similar to Practice Problem 31.
The gravitational field intensity is 8.09 N/kg[toward centre].

37. Solution is similar to Practice Problem 31.
The mass of Neptune is about 1.03×10^{26} kg.

Practice Problem Solutions

Student Textbook pages 670–671

38. Conceptualize the Problem

- Two *charges* are close together and therefore they exert a *force* on each other.
- *Work* must be done on or to the charges in order to bring them close to each other.
- Since work was done on or by a charge, it has *electric potential energy*.

Identify the Goal

The electric potential energy, E_Q, stored between the charges

Identify the Variables

Known	Implied	Unknown
$q_1 = +2.6\ \mu C$	$k = 9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}$	E_Q
$q_2 = -3.2\ \mu C$		
$r = 1.60$ m		

Develop a Strategy

Write the equation for electric potential energy between two charges.

The electric potential energy stored in the field between the charges is -4.7×10^{-2} J.

Calculations

$$E_Q = k\frac{q_1 q_2}{r}$$

$$E_Q = \frac{\left(9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}\right)(+2.6 \times 10^{-6}\ C)(-3.2 \times 10^{-6}\ C)}{1.60\ m}$$

$$E_Q = -4.68 \times 10^{-2}\ J$$

$$E_Q \cong -4.7 \times 10^{-2}\ J$$

Validate the Solution

The units cancel to give $N \cdot m = J$.

The sign is negative, indicating the electric potential energy is negative. A negative sign is correct for unlike charges, because work was done *by* one of the charges to get it from infinity to its present distance from the second charge.

39. Solution is similar to Practice Problem 38.
The kinetic energy per charge is 0.18 J.

40. Solution is similar to Practice Problem 38.
The separation of the charges is 5.1×10^2 m.

41. Solution is similar to Practice Problem 38.
The charges will have the magnitude of 1.55×10^{-4} C, and will have the same sign, either both positive or both negative.

Practice Problem Solutions

Student Textbook pages 678–679

42. Solution is similar to Practice Problem 20.
The electric field intensity is about 4.8×10^6 N/C, away from the charge.

43. Conceptualize the Problem

- A charge creates an *electric field*.
- At any point in the field, you can describe an *electric potential difference* between that point and a location an infinite distance away.
- Electric potential difference is a scalar quantity and depends only on the distance from the source charge and not the direction.

Identify the Goal

The distance, r, from a positive point charge at which the electric potential difference will have a particular value

Identify the Variables

Known	Implied	Unknown
$q = 8.2$ C	$k = 9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}$	r
$V = 5.0$ V		

Develop a Strategy
Use the equation for the electric potential difference at a point a distance r from a point charge.

Calculations

$$V = k\frac{q}{r}$$
$$r = k\frac{q}{V}$$
$$r = \left(9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{8.2\ \text{C}}{5.0\ \text{V}}$$
$$r = 1.476 \times 10^{10}\ \text{m}$$
$$r \cong 1.5 \times 10^{10}\ \text{m}$$

The distance from the point charge is 1.5×10^{10} m.

Validate the Solution

$$\frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\frac{\text{C}}{\text{V}} = \frac{(\text{N}\cdot\text{m})\text{m}}{\text{C}}\frac{1}{\text{V}} = \frac{(\text{J})\text{m}}{\text{C}}\frac{1}{\text{J/C}} = \text{m}$$

Note that this distance is 2300 times greater than Earth's radius, or 0.1 times the distance between Earth and the Sun.

44. Solution is similar to Practice Problems 38 and 43.
The electric potential energy of the system is 2.9×10^{-5} J.

45. Solution is similar to Practice Problem 43.
The charge has a sign and magnitude of -4.7×10^{-12} C.

46. Solution is similar to Sample Problem on student textbook pages 313 and 314.
The points of zero potential are 6.2 cm and 27 cm to the right of charge A.

47. Solution is similar to Practice Problem 43.
The electric potential difference at point P is 1.1×10^6 V.

48. Conceptualize the Problem
- The *electric potential difference* between two points is the algebraic difference between the individual potential differences of the points.

Identify the Goal
The electric potential difference, ΔV, between the two points

Identify the Variables

Known	Implied	Unknown
$V_X = +4.8$ V		ΔV
$V_Y = -3.2$ V		

Develop a Strategy
Use algebraic subtraction to determine the potential difference between the two points.

Calculations

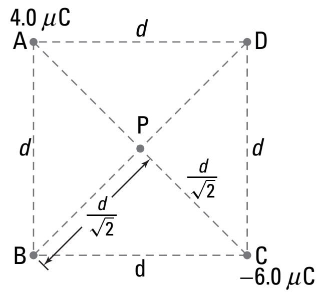
$$\Delta V = V_X - V_Y$$
$$\Delta V = 4.8\ \text{V} - (-3.2\ \text{V})$$
$$\Delta V = 8.0\ \text{V}$$

The electric potential difference between the two points is 8.0 V.

Validate the Solution
As the electric potential difference at one point is positive and the other is negative, the electric potential difference between the two points is expected to be greater than that at either point.

49. Solution is similar to Practice Problem 43.
The electric potential difference at point M is -2.1×10^6 V.

50. Solution is similar to Practice Problem 43.
The electric potential difference at point P is 1.6×10^6 V.



51. Conceptualize the Problem

- The *electric potential difference* due to the combination of charges is the *algebraic sum* of the electric potential differences due to *each point* alone.
- Designate charge A as the +4.0 μC charge, C as the −6.0 μC charge and B and D as the other two corners of the square. Let P be the intersection of the diagonals.
- Due to the symmetry of the charge arrangement, points B and D will always have the same potential. Therefore, it is only necessary to consider one of them (we consider point B in this solution).
- The size of the square is not given. Let the length of the sides be given by "*d*" and carry it through the calculation—perhaps it will cancel out.

Identify the Goal

The charge, q_P, required at the intersection of the diagonals of the square to make the potential difference zero at the unoccupied corners of the square

Identify the Variables

Known	Implied	Unknown
$q_A = 4.0\ \mu C$	$k = 9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}$	d
$q_C = -6.0\ \mu C$		q_P
		V (at B or D)

Develop a Strategy

Calculate the total potential difference at point B from each of the charges, including the unknown charge, together.

Calculations

$$V_{at\ B} = V_{A\ at\ B} + V_{C\ at\ B} + V_{P\ at\ B} = 0$$

$$k\frac{q_A}{d} + k\frac{q_C}{d} + k\frac{q_P}{\frac{d}{\sqrt{2}}} = 0$$

Use the Pythagorean theorem to find the distance from the unknown charge, q_P, to point B:

$$r^2 = \left(\frac{d}{2}\right)^2 + \left(\frac{d}{2}\right)^2 = \frac{d^2}{2} \text{ or, } r = \frac{d}{\sqrt{2}}.$$

$$q_A + q_C + \sqrt{2}q_P = 0$$

Note that the size of the square, d, cancels out of the calculation on the right.
Solve for the unknown charge.

$$q_P = \frac{-q_A - q_C}{\sqrt{2}}$$

$$q_P = \frac{-4.0\ \mu C - (-6.0\ \mu C)}{\sqrt{2}}$$

$$q_P = 1.414 \times 10^{-6}\ C$$

$$q_P \cong 1.4 \times 10^{-6}\ C$$

The required charge is 1.4×10^{-6} C.

Validate the Solution

The magnitude of the charge at point P is less than those at A or C, and the charge is closer to B (or D), so the result seems reasonable.

52. Conceptualize the Problem

- The *work* done per unit charge to move a charge from one point in the field to another is equal to the difference of the electric potentials at each of those two points.

- The difference of electric potentials is written as the final potential minus the initial potential.

Identify the Goal
The electric potential difference of point B, V_B

Identify the Variables

Known	Implied	Unknown
$q = 2.0$ C $W_{AB} = 8.0$ J $V_A = 6.0$ V		V_B

Develop a Strategy

Write down the equation for work done per unit charge.
Solve for V_B.

Calculations

$$\frac{W_{AB}}{q} = V_{\text{final}} - V_{\text{initial}}$$

$$\frac{W_{AB}}{q} = V_A - V_B$$

$$V_B = V_A - \frac{W_{AB}}{q}$$

$$V_B = 6.0\text{ V} - \frac{8.0\text{ J}}{2.0\text{ C}}$$

$$V_B = 2.0\text{ V}$$

The electric potential difference of point B was 2.0 V.

Validate the Solution
The electric potential difference of point B will be higher or lower than that at point A. If it was higher, the work done would be negative (because the charge is positive), therefore it is lower.

53. Solution is similar to Practice Problem 52.
The kinetic energy of the charge will be 12 J.

54. Solution is similar to Practice Problem 43.
The potential difference between the two points is -2.4×10^4 V.

55. Solution is similar to Practice Problem 52.
(a) The potential difference between point A and B is 1.9×10^5 V.
(b) The work required to move the second charge would be 1.2×10^{-3} J.
(c) A is at a higher potential.

56. Solution is similar to Sample Problem on student textbook pages 676 and 677.
The points of zero potential are 5.3 cm and 16 cm to the right of charge A.

57. Solution is similar to Sample Problem on student textbook pages 676 and 677.
The points of zero potential lie on a line that is perpendicular to the line that connects the charges and runs through the point midway between the two charges.

58. Solution is similar to Sample Problem on student textbook pages 676 and 677.
The points of zero potential are 3.4 cm above the origin and 24 cm below the origin.

59. Solution is similar to Sample Problem on student textbook pages 676 and 677.
q_2 can have any magnitude and its distance from q_1 is given by $\left(2.0\ \frac{\text{cm}}{\mu\text{C}}\right) q_2$ where q_2 is in μC and the distance is in cm.

60. Solution is similar to Sample Problem on student textbook pages 676 and 677. The point of zero potential difference will be 4.0 cm to the right of the negative charge.

Chapter 14 Review

Answers to Problems for Understanding

Student Textbook pages 684–685

18. The force of repulsion is 9×10^3 N.

$$|\vec{F}| = \frac{\left(9 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1 \text{ C})(1 \text{ C})}{\left(1 \times 10^3 \text{ m}\right)^2}$$

$$|\vec{F}| = 9 \times 10^3 \text{ N}$$

19. The force between the two free electrons is 2.3×10^{-8} N repulsive.

$$F = \frac{\left(9.0 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(1.6 \times 10^{-19} \text{ C}\right)\left(1.6 \times 10^{-19} \text{ C}\right)}{\left(1.0 \times 10^{-10} \text{ m}\right)^2}$$

$$|\vec{F}| \cong 2.3 \times 10^{-8} \text{ N}$$

20. The centres of the balls are 5.6×10^{-2} m apart.

$$|\vec{F}| = \frac{kq_1q_2}{r^2}$$

$$r = \sqrt{\frac{kq_1q_2}{|\vec{F}|}}$$

Use the positive root, since r is a distance.

$$r = \pm\sqrt{\frac{\left(9.0 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(8.0 \times 10^{-9} \text{ C}\right)\left(12.0 \times 10^{-9} \text{ C}\right)}{2.8 \times 10^{-4} \text{ N}}}$$

$$r = 5.6 \times 10^{-2} \text{ m}$$

21. The net force on each charge is as follows.

$$|\vec{F}_{\text{A on B}}| = |\vec{F}_{\text{B on A}}| = \frac{\left(9.0 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(2.0 \times 10^{-6} \text{ C})(4.0 \times 10^{-6} \text{ C})}{(1.0 \text{ m})^2}$$

$$|\vec{F}_{\text{A on B}}| = |\vec{F}_{\text{B on A}}| = 0.072 \text{ N}$$

$$|\vec{F}_{\text{A on C}}| = |\vec{F}_{\text{C on A}}| = \frac{\left(9.0 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(2.0 \times 10^{-6} \text{ C})(6.0 \times 10^{-6} \text{ C})}{(2.0 \text{ m})^2}$$

$$|\vec{F}_{\text{A on C}}| = |\vec{F}_{\text{C on A}}| = 0.027 \text{ N}$$

$$|\vec{F}_{\text{A on B}}| = |\vec{F}_{\text{B on A}}| = \frac{\left(9.0 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(4.0 \times 10^{-6} \text{ C})(6.0 \times 10^{6} \text{ C})}{(1.0 \text{ m})^2}$$

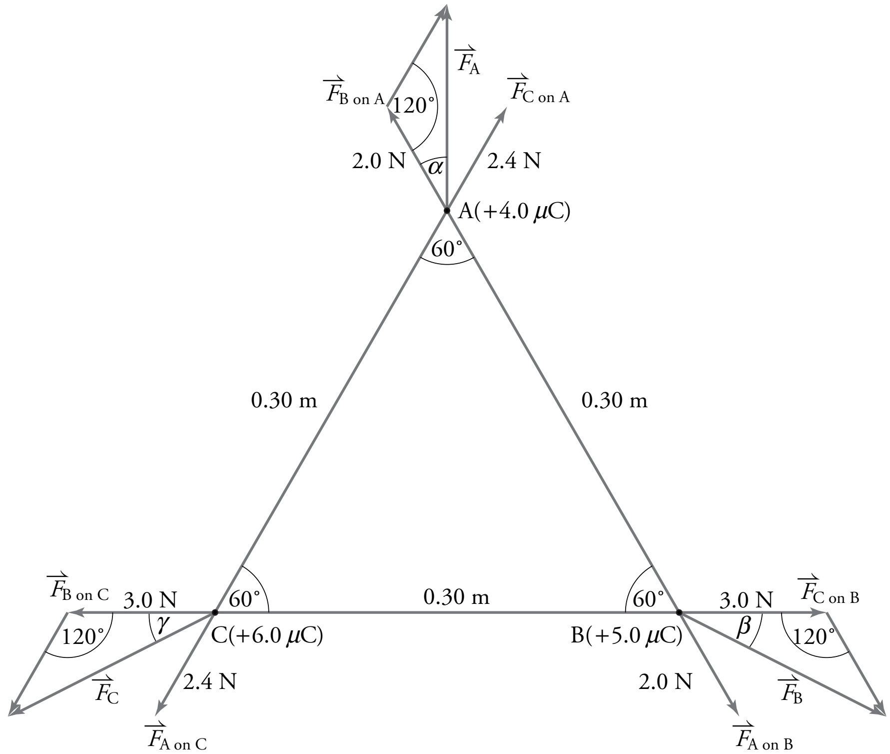
$$|\vec{F}_{\text{B on C}}| = |\vec{F}_{\text{C on B}}| = 0.216 \text{ N}$$

Let right be the positive direction and left be the negative direction.

$\vec{F}_{\text{net on A}} = -0.072 \text{ N} + 0.027 \text{ N}$ $\quad$ $\vec{F}_{\text{net on B}} = 0.072 \text{ N} + 0.216 \text{ N}$ $\quad$ $\vec{F}_{\text{net on C}} = -0.027 \text{ N} - 0.216 \text{ N}$

$\vec{F}_{\text{net on A}} = -0.045 \text{ N}$ $\quad$ $\vec{F}_{\text{net on B}} = 0.29 \text{ N}$ $\quad$ $\vec{F}_{\text{net on C}} = -0.24 \text{ N}$

22. The force on A is 3.8 N in a direction 153°clockwise from the line segment CA. The force on B is 4.4 N in a direction 157° counterclockwise from the line segment CB. The force on C is 3.8 N in a direction 154° clockwise from the line segment BC.



$$|\vec{F}_{A\text{ on }B}| = |\vec{F}_{B\text{ on }A}| = \frac{\left(9.0\times10^9\ \frac{N\cdot m^2}{C^2}\right)\left(4.0\times10^{-6}\ C\right)\left(5.0\times10^{-6}\ C\right)}{(0.30\ m)^2}$$

$$|\vec{F}_{A\text{ on }B}| = |\vec{F}_{B\text{ on }A}| = 2.0\ N$$

$$|\vec{F}_{A\text{ on }C}| = |\vec{F}_{C\text{ on }A}| = \frac{\left(9.0\times10^9\ \frac{N\cdot m^2}{C^2}\right)\left(4.0\times10^{-6}\ C\right)\left(6.0\times10^{-6}\ C\right)}{(0.30\ m)^2}$$

$$|\vec{F}_{A\text{ on }C}| = |\vec{F}_{C\text{ on }A}| = 2.4\ N$$

$$|\vec{F}_{B\text{ on }C}| = |\vec{F}_{C\text{ on }B}| = \frac{\left(9.0\times10^9\ \frac{N\cdot m^2}{C^2}\right)\left(5.0\times10^{-6}\ C\right)\left(6.0\times10^{-6}\ C\right)}{(0.30\ m)^2}$$

$$|\vec{F}_{B\text{ on }C}| = |\vec{F}_{C\text{ on }B}| = 3.0\ N$$

Use the law of cosines and the law of sines.

Force on A

$$F_A^2 = 2.0^2\ N^2 + 2.4^2\ N^2 - 2(2.0)(2.4)\cos 120^\circ\ N^2$$

$$F_A^2 = 14.56\ N^2$$

$$|\vec{F}_A| = 3.8\ N$$

$$\frac{\sin\alpha}{2.4} = \frac{\sin 120^\circ}{3.8}$$

$$\alpha = 33^\circ$$

Force on B

$$F_B^2 = 2.0^2\ N^2 + 3.0^2\ N^2 - 2(2.0)(3.0)\cos 120^\circ\ N^2$$

$$F_B^2 = 19\ N^2$$

$$|\vec{F}_A| = 4.4\ N$$

$$\frac{\sin\beta}{2.0} = \frac{\sin 120^\circ}{4.4}$$

$$\beta = 23^\circ$$

Force on C

$$F_C^2 = 3.0^2\ \text{N}^2 + 2.4^2\ \text{N}^2 - 2(3.0)(2.4)\cos 120^\circ\ \text{N}^2 \qquad \frac{\sin\gamma}{2.4} = \frac{\sin 120^\circ}{4.7}$$

$$F_{C^2} = 21.96\ \text{N}^2 \qquad \gamma = 26^\circ$$

$$|\vec{F}_C| = 4.7\ \text{N}$$

23. The electrostatic force is about 2.3×10^{39} times stronger than the gravitational force.

$$F_G = \frac{Gm_1m_2}{r^2} = \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(1.67 \times 10^{-27}\ \text{kg}\right)\left(9.1 \times 10^{-31}\ \text{kg}\right)}{\left(5.3 \times 10^{-11}\ \text{m}\right)^2} = 3.6 \times 10^{-47}\ \text{N}$$

$$F_Q = \frac{kq_1q_2}{r^2} = \frac{\left(9.0 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(1.60 \times 10^{-19}\ \text{C}\right)\left(1.60 \times 10^{-19}\ \text{C}\right)}{\left(5.3 \times 10^{-11}\ \text{m}\right)^2} = 8.2 \times 10^{-8}\ \text{N}$$

$$\frac{|\vec{F}_Q|}{|\vec{F}_g|} = \frac{8.2 \times 10^{-8}\ \text{N}}{3.6 \times 10^{-47}\ \text{N}}$$

$$\frac{|\vec{F}_Q|}{|\vec{F}_g|} \cong 2.3 \times 10^{39}$$

24. Approximate opposite charges for Earth and the Moon would be 4.0×10^{14} C and 8.1×10^{12} C, respectively. Assume that the charges on Earth (q_E) and the Moon (q_M) would be proportional to their respective volumes.

$$q_E = \left(\frac{r_E}{r_M}\right)^3 q_M$$

$$q_E = \left(\frac{6.38 \times 10^6\ \text{m}}{1.74 \times 10^6\ \text{m}}\right)^3 q_M$$

$$q_E = 49.3q_M$$

For the Coulombic force to be equal to the gravitational force, $\dfrac{Gm_Em_M}{r^2} = \dfrac{kq_Eq_M}{r^2}$.

$$\left(6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}\right)(5.98 \times 10^{24}\ \text{kg})(7.36 \times 10^{22}\ \text{kg}) = \left(9.0 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(49.3\text{q}_M)(\text{q}_M)$$

$$q_M^2 = 6.6 \times 10^{25}\ \text{C}^2 \qquad \text{and} \qquad q_E = 49.3q_M$$

$$q_M = 8.1 \times 10^{12}\ \text{C} \qquad q_E = 4.0 \times 10^{14}\ \text{C}$$

Note: You might want to calculate relative charges using surface areas rather than volumes.

25. The ratio of the electric force to the gravitational force is 4.2×10^{42}.

$$\frac{\frac{kq_eq_e}{r^2}}{\frac{Gm_em_e}{r^2}} = \frac{kq^2}{Gm^2}$$

$$\frac{kq^2}{Gm^2} = \frac{\left(9.0 \times 10^9\right)\left(1.6 \times 10^{-19}\right)^2\ \text{N}}{\left(6.7 \times 10^{-11}\right)\left(9.1 \times 10^{-31}\right)^2\ \text{N}}$$

$$\frac{kq^2}{Gm^2} = 4.2 \times 10^{42}$$

26. The charge on the 0.30 g pith ball is −57 C.

$$|\vec{F}_a| = |\vec{F}_g|$$

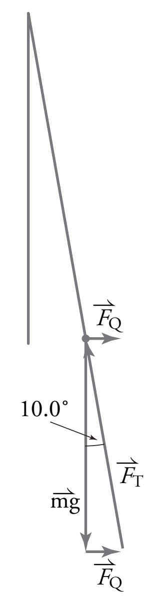
$$qE = mg$$

$$q = \frac{\left(0.30 \times 10^{-3}\ \text{kg}\right)\left(9.81\ \frac{\text{N}}{\text{kg}}\right)}{5.2 \times 10^{-5}\ \frac{\text{N}}{\text{C}}}$$

$q = -57$ C (negative, since upward force from a downward field)

27. The electric force exerted on the 3.0 g Ping-Pong™ ball is 5.2×10^{-3} N away from the comb.

$$\tan 10.0^\circ = \frac{F_Q}{mg}$$
$$F_Q = mg \tan 10.0^\circ$$
$$F_Q = (3.0 \times 10^{-3}\ \text{kg})\left(9.8\ \frac{\text{N}}{\text{kg}} \times 0.176\right)$$
$$F_Q = 5.2 \times 10^{-3}\ \text{N}$$



28. (a) The mass of Uranus is 8.66×10^{25} kg.

$$g = \frac{Gm_U}{r^2} \qquad m_U = \frac{g(r_U + h)^2}{G}$$
$$g = \frac{Gm_U}{(r_U + h)^2} \qquad m_U = \frac{8.71\ \frac{\text{N}}{\text{kg}}\left(2.56 \times 10^7\ \text{m} + 1.50 \times 10^5\ \text{m}\right)^2}{6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}}$$
$$m_U = 8.66 \times 10^{25}\ \text{kg}$$

(b) The gravitational field intensity is 8.81 N/kg at the surface of Uranus.

Since $g \propto \frac{1}{r^2}$,
$$g_{\text{surface}} = \frac{\left(2.56 \times 10^7\ \text{m} + 1.50 \times 10^5\ \text{m}\right)^2}{\left(2.56 \times 10^7\ \text{m}\right)^2} \times 8.71\ \frac{\text{N}}{\text{kg}}$$
$$g_{\text{surface}} = 8.81\ \frac{\text{N}}{\text{kg}}$$

(c) A 100 kg person would weigh 8.81×10^2 N on Uranus.

$$F = mg$$
$$F = (8.81\ \text{N/kg})\left(1.00 \times 10^2\ \text{kg}\right)$$
$$F = 8.81 \times 10^2\ \text{N}$$

29. The planet would have a surface gravitational field intensity 2/9 as strong as Earth's.

Since $g \propto \frac{M}{r^2}$,
$$g_P = \frac{2}{3^2} g_E$$
$$g_P = \frac{2}{9} g_E$$

30. (a) The force between the two particles would be 8.22×10^{-18} N.

$$|\vec{F}_{\mathrm{Q}}| = \frac{kq_1q_2}{r^2}$$

$$|\vec{F}_{\mathrm{Q}}| = \frac{\left(8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}\right)\left(1.60 \times 10^{-19}\ \mathrm{C}\right)^2}{\left(5.29 \times 10^{-11}\ \mathrm{m}\right)^2}$$

$$|\vec{F}_{\mathrm{Q}}| = 8.22 \times 10^{-8}\ \mathrm{N}$$

The gravitational force is negligible, as shown in answer 23.

(b) The speed of the electron is 2.18×10^6 m/s.

$$F_{\mathrm{c}} = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{F_{\mathrm{c}}r}{m}}$$

$$v = \sqrt{\frac{\left(8.22 \times 10^{-8}\ \mathrm{N}\right)\left(5.29 \times 10^{-11}\ \mathrm{m}\right)}{9.11 \times 10^{-31}\ \mathrm{kg}}}$$

$$v = 2.18 \times 10^6\ \frac{\mathrm{m}}{\mathrm{s}}$$

(c) The electric field that the electron experiences is 5.14×10^{11} N/C toward the proton.

$$|\vec{E}| = \frac{kq}{r^2}$$

$$|\vec{E}| = \frac{\left(8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}\right)\left(1.60 \times 10^{-19}\ \mathrm{C}\right)}{(5.29 \times 10^{-11}\ \mathrm{m})^2}$$

$$E = 5.14 \times 10^{11}\ \frac{\mathrm{N}}{\mathrm{C}}\ \text{toward proton}$$

(d) The electric potential difference that the electron experiences is 27.2 V.

$$V = Er$$

$$V = \left(5.15 \times 10^{11}\ \frac{\mathrm{N}}{\mathrm{C}}\right)\left(5.29 \times 10^{-11}\ \mathrm{m}\right)$$

$$V = 27.2\ \mathrm{V}$$

31. The mass that the electron should have is 1.86×10^{-9} kg, which is 2.04×10^{21} times larger than the actual mass.

$$\frac{\left(6.67 \times 10^{-11}\ \frac{\mathrm{N \cdot m^2}}{\mathrm{kg^2}}\right)\left(m^2\right)}{r^2} = \frac{\left(8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}\right)\left(1.60 \times 10^{-19}\ \mathrm{C}\right)^2}{r^2}$$

$$m = \sqrt{\frac{\left(8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}\right)\left(1.60 \times 10^{-19}\ \mathrm{C}\right)^2}{6.67 \times 10^{-11}\ \frac{\mathrm{N \cdot m^2}}{\mathrm{kg^2}}}}$$

$$m = 1.86 \times 10^{-9}\ \mathrm{kg}$$

$$\text{ratio} = \frac{1.86 \times 10^{-9}\ \mathrm{kg}}{9.11 \times 10^{-31}\ \mathrm{kg}}$$

$$\text{ratio} = 2.04 \times 10^{21}$$

32. $\vec{F} = q\vec{E}$, so tripling the charge will triple the force; changing from positive to negative charge will reverse the direction of the force. Therefore, $\vec{F} = 9 \times 10^{-5}$ N[W].

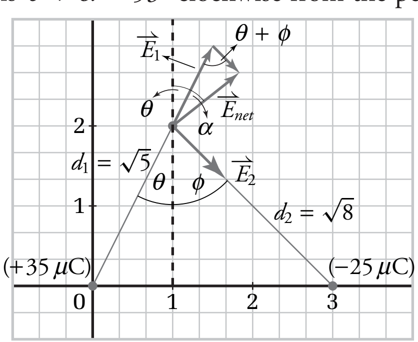
33. The separation is 0.51 m.

$$E_Q = \frac{kq_1q_2}{r}$$
$$r = \frac{kg_1q_2}{E_Q}$$
$$r = \frac{\left(9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(1.5 \times 10^{-6}\ \text{C}\right)\left(6.0 \times 10^{-6}\ \text{C}\right)}{0.16\ \text{J}}$$
$$r = 5.1 \times 10^{-1}\ \text{m}$$

34. The electric field at (1,2) is 6.1×10^4 N/C in a direction 53° clockwise from the perpendicular.

$$d_1 = \sqrt{1^2 + 2^2} \qquad \text{and} \qquad d_2 = \sqrt{2^2 + 2^2}$$
$$d_1 = \sqrt{5} \qquad\qquad\qquad d_2 = \sqrt{8}$$
$$|\vec{E_1}| = \frac{\left(9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(35 \times 10^{-6}\ \text{C}\right)}{\left(\sqrt{5}\ \text{m}\right)^2}$$
$$\vec{E_1} = 6.3 \times 10^4\ \frac{\text{N}}{\text{C}}\ \text{away from } (0, 0)$$
$$\tan\theta = \frac{1}{2} = 1,\ \text{so}\ \theta = 26.6^\circ$$
$$|\vec{E_2}| = \frac{\left(9.0 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(25 \times 10^{-6}\ \text{C}\right)}{\left(\sqrt{8}\ \text{m}\right)^2}$$
$$\vec{E_2} = 2.8 \times 10^4\ \frac{\text{N}}{\text{C}}\ \text{toward } (3,\ 0)$$
$$\tan\phi = \frac{2}{2},\ \text{so}\ \phi = 45^\circ$$
$$\theta + \phi = 71.6^\circ$$
$$E_{net}^2 = \left(6.3 \times 10^4\right)^2 \frac{\text{N}^2}{\text{C}^2} + \left(2.8 \times 10^4\right)^2 \frac{\text{N}^2}{\text{C}^2} - 2\left(6.3 \times 10^4\right)\left(2.8 \times 10^4\right)\cos 72^\circ\ \frac{\text{N}^2}{\text{C}^2}$$
$$|\vec{E}_{net}| = 6.1 \times 10^4\ \frac{\text{N}}{\text{C}}$$
$$\frac{\sin\alpha}{2.8} = \frac{\sin 71.6^\circ}{6.1}$$
$$\alpha = 26^\circ$$

The direction of $\vec{E}_{net}$ is $\theta + \alpha = 53^\circ$ clockwise from the perpendicular at (1,2).



35. (a) The change in potential energy is

$$q\Delta V = \left(-15 \times 10^{-9}\ \text{C}\right)(9 - 4)\ \text{V}$$
$$q\Delta V = -8 \times 10^{-8}\ \text{J}$$

(b) Some of the potential energy of the charge is converted into other forms of energy, such as kinetic energy or heat.

36. The work done is

$$W = q\Delta V$$
$$W = \left(180 \times 10^{-9}\ \text{C}\right)(8\ \text{V} - 24\ \text{V})$$
$$W = -3 \times 10^{-6}\ \text{J}$$

The negative sign indicates that work is done on the charge by the field.

37. (a) Assuming that the charge is effectively all located at the centre of the sphere

$$V = \frac{kq}{r}$$
$$V = \frac{\left(9.0 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(75 \times 10^{-9}\ \text{C}\right)}{15 \times 10^{-2}\ \text{m}}$$
$$V = 4.5 \times 10^{3}\ \text{V}$$

(b) Yes, the electrons on a conducting surface will move until distributed such that the surface is equipotential.

(c) The charges are approximately 63 nC on the larger sphere and 12 nC on the smaller sphere. The two spheres will have approximately the same amount of charge per unit area and area is proportional to r^2, so

$$\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2}$$
$$q_1 = \frac{15^2}{6.5^2} q_2$$
$$q_1 = 5.33 q_2$$

Since $q_1 + q_2 = 75 \times 10^{-9}$ C, $5.33q_2 + q_2 = 75 \times 10^{-9}$ C

$$q_2 = \frac{75 \times 10^{-9}\ \text{C}}{6.33} \quad \text{and} \quad q_1 = 75\ \text{nC} - 12\ \text{nC}$$
$$q_2 = 12\ \text{nC} \qquad q_1 = 63\ \text{nC}$$

38. (a) The electric field vectors at the midpoint will be equal but opposite; therefore, the net electric field equals zero. The potential difference between P and infinity is

$$V_{\text{net}} = \frac{kq}{r}$$
$$V_{\text{net}} = \left(9.0 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(\frac{6.0 \times 10^{-6}\ \text{C}}{0.50\ \text{m}}\right) + \left(9.0 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(\frac{6.0 \times 10^{-6}\ \text{C}}{0.50\ \text{m}}\right)$$
$$V_{\text{net}} = 2.2 \times 10^{5}\ \text{V}$$

(b) With one of the charges negative and the other positive, the electric field vectors will both point *away from* the positive charge and their magnitudes will add, so

$$|\vec{E}_{\text{Q}}| = \frac{\left(9.0 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(6.0 \times 10^{-6}\ \text{C}\right)}{(0.50\ \text{m})^2} \times 2$$
$$\vec{E}_{\text{Q}} = 4.3 \times 10^{5}\ \frac{\text{N}}{\text{C}}\ \text{away from positive charge}$$

The two scalar quantities for the electric potential difference will be equal but opposite, so the net electric potential difference adds to zero.

(c) Changes in variables affect vector and scalar quantities differently.

39. (a) 2.3 J of work must be done.

$$W = \Delta E_Q$$

$$W = \Delta \frac{kq_1q_2}{r}$$

$$W = \frac{\left(9.0 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}\right)(8.0 \times 10^{-6}\ \mathrm{C})(2.0 \times 10^{-6}\ \mathrm{C})}{(30.0 \times 10^{-3}\ \mathrm{m})} - \frac{\left(9.0 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}\right)(8.0 \times 10^{-6}\ \mathrm{C})(2.0 \times 10^{-6}\ \mathrm{C})}{(58 \times 10^{-3}\ \mathrm{m})}$$

$$W = 2.3\ \mathrm{J}$$

(b) The potential difference is 1.2×10^6 V.

$$\Delta V = \frac{W}{q}$$

$$\Delta V = \frac{2.3\ \mathrm{J}}{2.0 \times 10^{-6}\ \mathrm{C}}$$

$$\Delta V = 1.2 \times 10^6\ \mathrm{V}$$

(c) Point X, which is closer to the positive point charge, is at the higher potential.

40. (a) The potential difference is 4.0×10^5 V.

$$\Delta V = \frac{kq}{r_2} - \frac{kq}{r_1}$$

$$\Delta V = \left(9.0 \times 10^9 \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}\right)(6.8 \times 10^{-6}\ \mathrm{C})\left(\frac{1}{5.9 \times 10^{-2}\ \mathrm{m}} - \frac{1}{9.6 \times 10^{-2}\ \mathrm{m}}\right)$$

$$\Delta V = 4.0 \times 10^5\ \mathrm{V}$$

(b) Being closer to the positive charge, point R is at the higher potential.