

SPH4UI

Unit 3: Fields

Unit 3 Overview

Lesson	Text Reference	Topic	Questions	Done
1	6.1	Gravitational Fields	Pg 293 P#3; Pg 295 P# 1; Pg 296 Q#4, 5, 9, 11, 13	
2	6.2	Orbits	Pg 303 Q#6, 8, 14	
L3.1	--	Orbit of Stars around a Black Hole	Lab Write-up & Discussion	
3	7.1 & 7.2	Electrostatics & Coulomb's Law	Pg 333 Q#2, 3, 7 – 10 W/S Coulombs Law #1, 2, 3	
4	7.2	Coulomb's Law 2		
5	7.3	Electric Fields 1	Pg 345 Q#2 – 4, 6, 7 + W/S #4, 5, 6	
6		Electric Fields 2		
7	7.5	Electric Potential	Pg 360 P#1 – 4; Pg 361 Q#4 – 6	
L3.2	--	Mapping Electric Fields	Lab Write-up & Discussion	
8	7.4	Motion of Charged Particles in Electric Fields	Pg 353 P#1 – 3; Pg 354 Q#1 – 8	
9	8.1, 8.2 & 8.3	Magnetic Theory & Magnetic Fields	Pg 385 Q#3; Pg 391 Q#2, 4 – 7; Pg 396 Q#1 – 4	
10	8.4 & 8.5	Applications of Magnetic Fields	Pg 401 P#1 – 4; Pg 404 Q#2 – 6	

Lesson 1 – Gravitational Fields

The forces associated with gravity, electricity and magnetism are all *distributed* through fields.

A **field** is a point in three-dimensional space in which a property or quantity, such as force, may be distributed.

In brief, forces that act at a distance (those that do not require any contact) have an associated field.

Newtonian Gravitation

In grade 11 we studied the Universal Law of Gravitation as explained by Newton. Given any two masses m_1 and m_2 , and their centre-to-centre separation r , we can calculate the force of attraction between them using the relationship

$$F_g = \frac{Gm_1m_2}{r^2}$$

Where G is the gravitation constant and carries a value of $6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$.

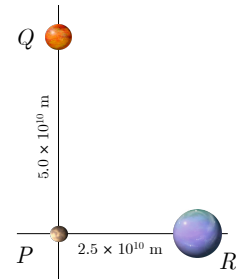
--	--	--

Example 1

The centres of two stone spheres sit a distance of 0.25 m apart. If each sphere has a mass of 3.0 kg, determine the magnitude of the gravitational force of attraction between them.

Example 2

Three planetoids are arranged as shown in the diagram to the right. Planetoid P has a mass of 2.0×10^{20} kg, planetoid Q has a mass of 4.0×10^{20} kg and planetoid R has a mass of 8.0×10^{20} kg. Determine the force acting on planetoid P .

**Gravitational Fields**

A gravitational field is made up of an infinite number of vectors which, taken together, define the magnitude and direction of the gravitational force for any object with mass.

The gravitational field strength is simply the magnitude of the gravitational field. We can determine it as follows:

**Example 3**

Calculate the gravitational field strength on the “surface” of Saturn. Assume that Saturn has a mass of 5.69×10^{26} kg and a radius of 6.03×10^7 m.

Lesson 1b – The Energy of Gravitational Fields

The Potential Energy of Gravity

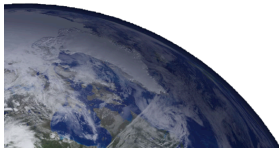
We have learned a little about gravitational potential energy. We might recognize it in terms of the common expression

$$E_g = mg\Delta h$$

But we have yet to consider the potential energy of gravity on a much larger scale.

Objects at different distances from the Earth (or any mass) experience different potential energies. And because the force of gravity is *attractive*, it takes energy for objects to break free from Earth's pull. One could think of **gravity** as an energy well. When an object is in the **gravitational well** of another mass, energy is required to move it out of the well because the mass attracts it.

Think of the Earth:



When very large distances are involved we use Newton's Law of Gravitation and some integral calculus to determine an expression for gravitational potential energy:

$$E_g = -\frac{Gm_1m_2}{r}$$

The negative sign indicates the "well-like" nature of the gravitational field; in order to break free from it, you need to supply energy. If you are interested in this derivation (it is beyond the scope of our course) you can check it out in our textbook or online.

Example 1

How much work is done moving a 1000 kg spacecraft from Earth's surface to a height of 200 km above Earth's surface?

Escape Velocity

Now that we know the amount of potential energy that must be overcome to escape Earth's gravitational field, we can calculate the amount of kinetic energy required and as such, the velocity needed to escape.

Who said rocket science was hard?

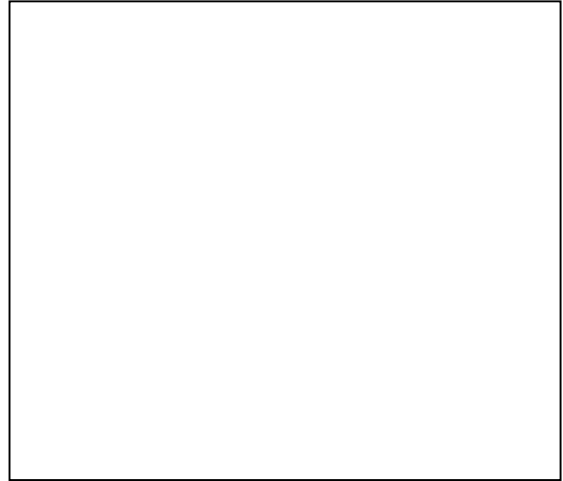
Example 2

Find the escape speed of both the Earth and the Moon. The mass of Earth is 5.98×10^{24} kg, the mass of the Moon is 7.35×10^{22} kg, Earth's radius is 6.38×10^6 m and the Moon's diameter is 3476 km.

Lesson 2 – Orbits

Thought experiment:

- ✓ If we throw a baseball, it lands (comes back to Earth) very quickly.
- ✓ If we fire a bullet, the projectile will travel a much farther distance before landing.
- ✓ If we launch a high power model rocket, it could travel hundreds of kilometers before landing.



The point is that, hypothetically, if we launch an object fast enough, it will go around the entire world. This is orbit.

At a constant velocity, objects traveling in a circle will experience centripetal motion. We can determine an expression for orbital speed using expressions we already know.

Example 1

What speed is required for an object to stay in orbit just above the Earth's surface?

This is an incredibly fast velocity and is one of the reasons why commercial airplanes do not escape the pull of gravity – they fly at speeds approaching 1000 km/h or 280 m/s.

Another reason is the atmosphere – traveling at velocities close to 8000 m/s (29 000 km/h) produce extreme amounts of air resistance, or drag (friction), which causes intense heat.

Example 2

What is the speed of the International Space Station in its typical orbit of 340 km above the Earth's surface?

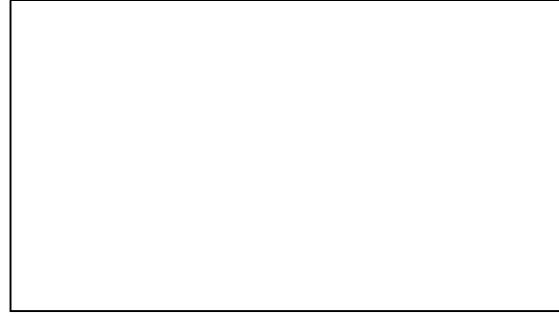
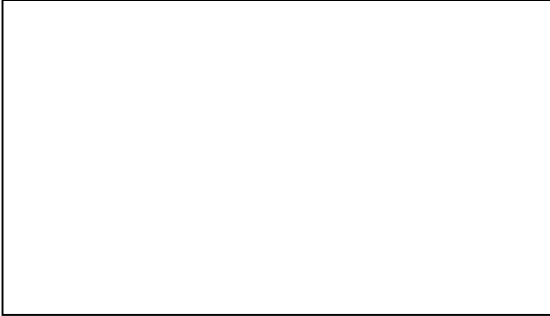
Kepler's Laws of Planetary Motion

Johannes Kepler struggled with the problem of planetary motion. The view held at the time was that everything in the universe traveled around the Sun in perfect circular orbits. His observations did not match this view and so he ventured onto other geometric possibilities. Eventually, he tried elliptical paths and the solutions matched his observations perfectly! He formulated three laws of planetary motion.

Law 1:

Law 2:

Law 3:



Example 3

Io, a small moon of Jupiter, has an orbital radius of 4.22×10^5 km. If its period is 1.77 days, determine the mass of Jupiter.

Lesson 3 – Electrostatics & Coulomb's Law

We had the chance to discuss the concept of gravitational fields for the past two lessons. Gravity is an example of a force that acts at a distance. The Electric and Magnetic forces are also examples that act at a distance and thus, behave in a similar manner to gravity.

Some Basics

Matter, as you know, is made of tiny particles called atoms. The current model of the atom consists of positive protons and neutral neutrons in the nucleus surrounded by probability clouds of electrons.

Law of Electric Charges

Opposite charges attract each other.

Like charges repel each other.

Charged objects attract some neutral objects.

Electric charge is the result of an excess or deficit of electrons. The positively charged protons in the nucleus do not move. An electroscope is a device used to detect the movement of electrons.

Transfer of Charge

Transfer of electrons happens through three methods: friction, contact and induction. Use your text to summarize each.

Friction	Contact	Induction

Coulomb's Law

Due to the fact that electrons are tiny point particles, we can't actually count individual electrons. Scientists have grouped electrons into "packages" of charge.

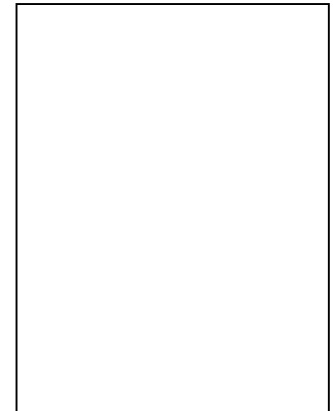
- Each bundle or package of charge contains the same number of electrons and has a unit of 1 Coulomb (C).
- Millikan, in 1911, found that there are 6.25×10^{18} electrons in a Coulomb.
- The total charge on an object can be found using the formula:

$$Q = N e$$

Where Q is the total charge in Coulombs, N is the number of electrons and e is the charge of one electron (1.602×10^{-19}).

We also know that like charges repel and unlike charges attract. But the cause of any repulsion or attraction there is some associated force – what is this force? This is what Coulomb set out to find.

By charging spheres with different magnitudes and varying the distances between them, Coulomb discovered the relationship between distance, magnitude of charge and the electrostatic force.



By combining these proportionalities we obtain:

Here, F_e is the electric force in Newtons, q_1 and q_2 are the magnitudes of the charges in Coulombs, and r is the distance between their centres in metres.

The proportionality constant, k , is given by $k = 9 \times 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}$. It is often expressed as

$k = \frac{1}{4\pi\epsilon_0}$, where ϵ_0 is the permittivity of free space and has a value of $8.854 \times 10^{-12} \text{C}^2/\text{Nm}^2$.

You should note two observations:

- ✓ The form of this equation is very similar to that of gravity – an inverse square law.
- ✓ If $F_e > 0$, the charges repel. If $F_e < 0$, the charges attract.

Example 1

Two positive charges, $q_1 = 1.6 \times 10^{-10} \text{ C}$ and $q_2 = 3.2 \times 10^{-10} \text{ C}$, are separated by 0.02 m. What is the magnitude and direction of the electrostatic force on particle 1 from particle 2?

Example 2

The force between two charges is $5 \times 10^{-5} \text{ N}$. If the distance between the charges is quadrupled, how does the force change?

Lesson 4 – Coulomb's Law 2

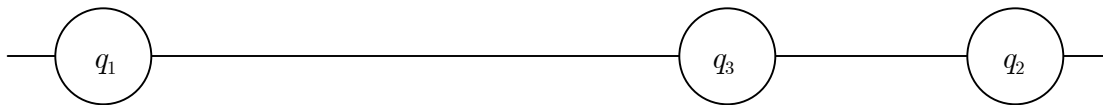
Until this point, we have considered the force acting between two charged point particles only. This limits our discussion of Coulomb's Law and we must now turn our attention to situations where there are more than two charges interacting.

The **principle of superposition** is a general principle and can be applied in many different situations (gravity and wave theory are common examples.) It states that a net effect is the sum of individual effects.

For n interacting particles:



Consider the following figure,



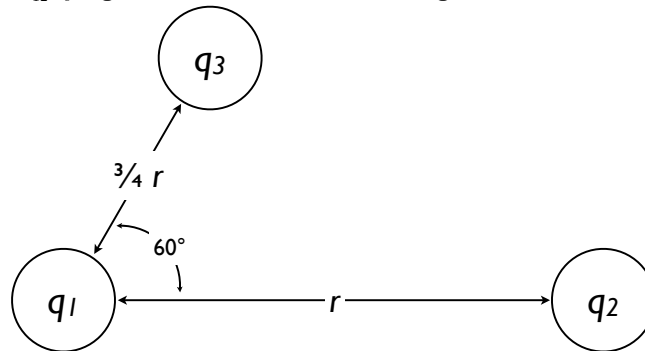
If we calculate the force acting on particle 1 from particle 2 using Coulomb's Law, we note that the presence of particle 3 has no effect. Likewise, we can compute the force on particle 1 from particle 3 and the presence of particle 2 has no effect.

Example 1

Using the figure above, find the magnitude and direction of the force on particle 1 from particles 2 and 3 if $q_1 = 1.6 \text{ C}$, $q_2 = 3.2 \text{ C}$, $q_3 = -3.2 \text{ C}$, $r = 0.02 \text{ m}$ and q_3 is $\frac{3}{4} r$ from q_1 .

Example 2

Find the electrostatic force on particle 1 using the figure below if $q_1 = 1.6 \text{ C}$, $q_2 = 3.2 \text{ C}$, $q_3 = -3.2 \text{ C}$, $r_{12} = 0.02 \text{ m}$ and $r_{13} = \frac{3}{4} r_{12}$ lying on a line that makes an angle of 60° to the horizontal.

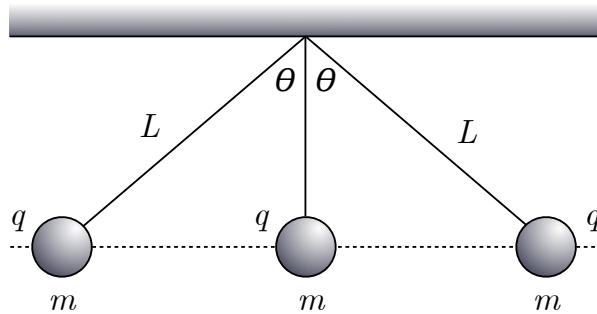


Worksheet

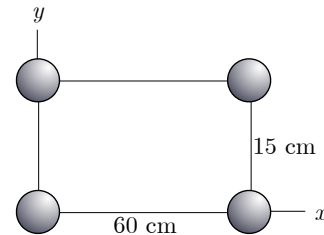
Coulomb's Law & Electric Fields

1. What magnitude of charge must be placed equally on the Earth and the Moon to make the magnitude of the electrical force between these two bodies equal the gravitational force between them? **Ans: 57.1 TC**

2. Three identical point charges, each of mass $m = 0.100$ kg and charge q , hang from three strings as shown. If the lengths of the left and right strings are $L = 30.0$ cm and angle $\theta = 45.0^\circ$, determine the value of q .

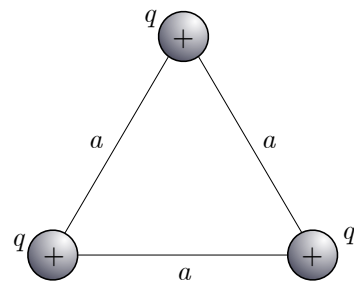


3. Four identical point charges ($q = +10.0 \mu\text{C}$) are located on the corners of a rectangle with dimensions as shown. Calculate the magnitude and direction of the electric force exerted on the charge at the lower left corner by the other three charges. **Ans: $(-4.9\hat{i} - 40.6\hat{j})$ N**



4. An object having a net charge of $24 \mu\text{C}$ is placed in a uniform electric field of 610 N/C directed vertically. What is the mass of the object if it "floats" in the field?
5. Two $2.0 \mu\text{C}$ charges are located on the x axis. One is at $x = +1.0$ m, the other at $x = -1.0$ m. (a) Determine the electric field on the y -axis at $y = 0.50$ m. **Ans: $(1.29 \times 10^4 \hat{j})$ N/C** (b) Calculate the electric force on a $-3.0 \mu\text{C}$ charge at this location. **Ans: $(-3.87 \times 10^{-2} \hat{j})$ N**

6. Three equal positive charges q are at the corners of an equilateral triangle of side length a as shown. (a) At what point in the plane of the charges is the electric field zero (other than at ∞)? Sketch the electric field for this distribution of charges. (b) What are the magnitude and direction of the electric field at P due to the two charges at the base



of the triangle? **Ans: $\frac{\sqrt{3} kq}{a^2} \hat{j}$**

Lesson 5 – Electric Fields 1

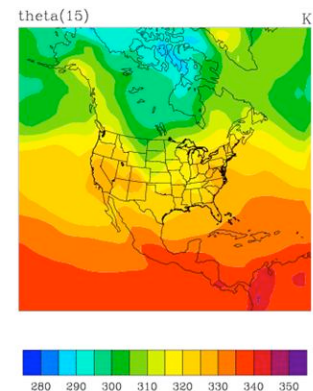
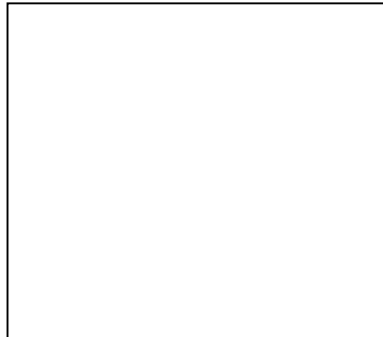
In our analogy of gravitational fields, we said that a mass in free space would generate a “pulling force” whether or not there is a second mass present. Electric charges are similar – charge creates a “pulling/pushing force” even if a second charge is not present. But instead of thinking of this pull (or push) as a *force* we call it a *field* (afterall, it can’t be a force if there isn’t a second object there).

Recall:

A **field** is a point in three-dimensional space in which a property or quantity, such as force, may be distributed.

Suppose we place a point charge, q_1 , on a Cartesian coordinate system and then bring another charge, q_2 , near it. Coulomb’s Law tells us that they exert a force on each other (i.e. they either attract or repel). But how does each charge know that the other is there? The answer lies in the electric field produced by the charges.

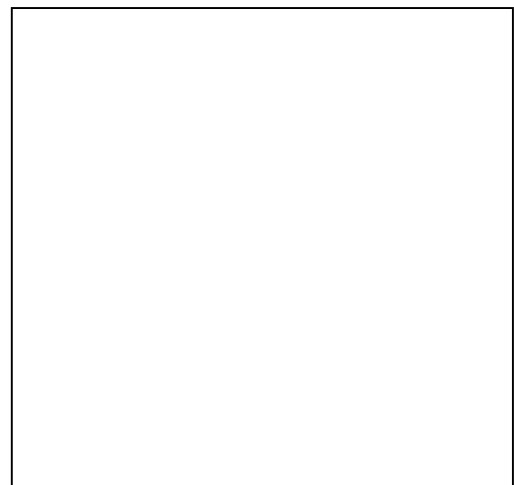
If we measure the temperature at 10 points in this room, the result would be a temperature field. This is a scalar field with no direction.



A test charge is brought close to a fixed array of charges from several different starting locations. Map the path of the test charge.

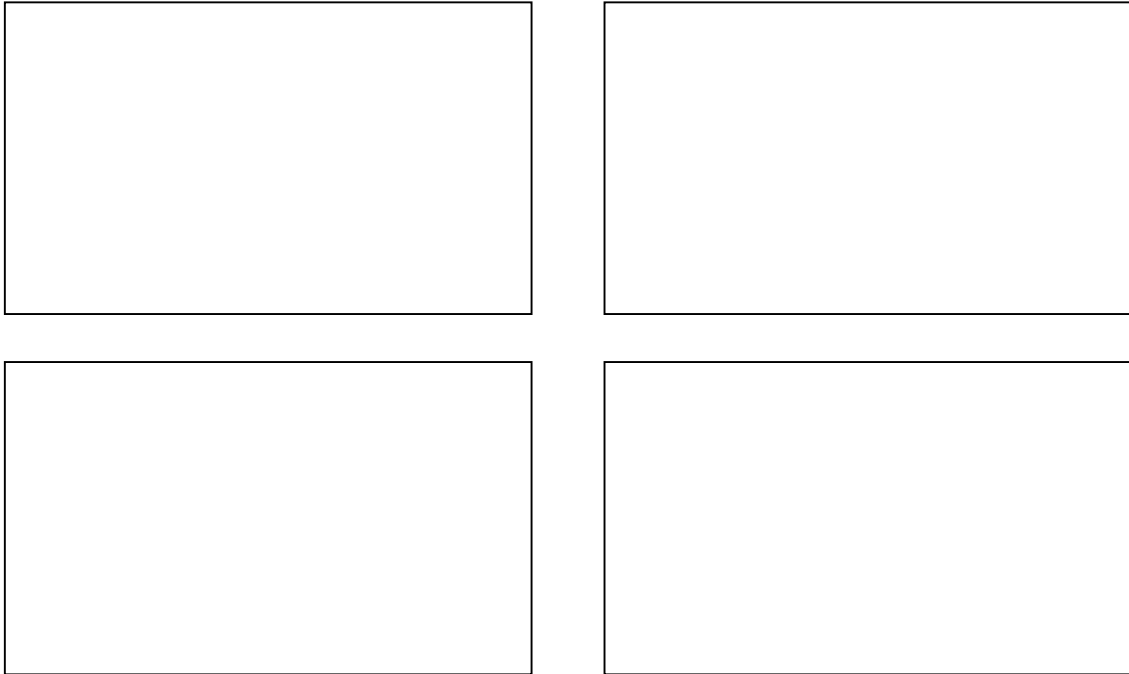
The path of the motion from each starting location is what maps the electric field. An electric field is a vector field, thus a test charge will feel not only the magnitude of the force from each of the other charges but will also be pulled in a direction because of the other charges.

If we were to place test charges all over the place and find the path that each took, we would end up with a lot of lines of force and these are known as electric field lines.



Example 1

Draw the electric field lines for each of the following arrays of charge.

**Field Strength**

We can also measure the strength of the electric field on the test charge by

$$\vec{\mathcal{E}} = \frac{\vec{F}_e}{q_t}$$

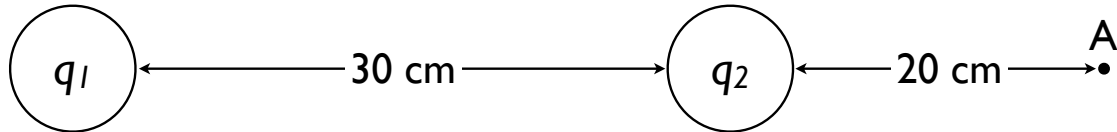
Where $\vec{\mathcal{E}}$ is the electric field strength in N/C, \vec{F}_e is the electric force in N at a point in the field, and q_t is the charge of the test particle in C.

For a single charge we can determine an equation for field strength:

As with Coulomb's Law, electric field strength obeys the principal of superposition, thus, the electric field generated by multiple objects is a vector sum of the individual fields.

Example 2

Two point charges, $q_1 = 3.6 \times 10^{-6} \text{ C}$ and $q_2 = -2.7 \times 10^{-6} \text{ C}$ are arranged as shown in the diagram below.



- Find the net electric field at point A.
- What force is exerted on a test charge of $4.5 \times 10^{-6} \text{ C}$ placed at point A?

Lesson 6 – Electric Fields 2

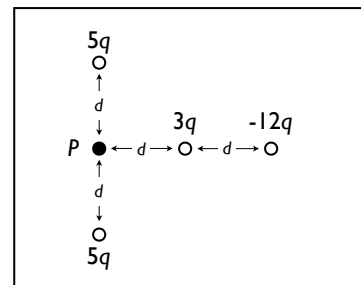
Today, we'll take a look at some challenging charge distributions and find the associated electric fields.

Example 1

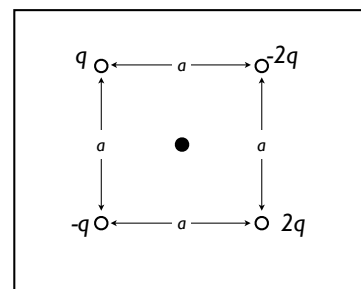
For a charge $q_1 = 7.0 \mu\text{C}$ located at the origin and a charge $q_2 = -5.0 \mu\text{C}$ located on the x -axis 0.3 m from the origin, find the electric field at the point P with coordinates (0, 0.40) m.

Partner Problem Solving:

1. What is the electric field at point P due to the four point charges shown? **Ans: 0 N/C**



2. What is the electric field at the centre of the square shown if $q = 1.0 \times 10^{-8} \text{ C}$ and $a = 5.0 \text{ cm}$? **Ans:**
 $(1.02 \times 10^5 \hat{j}) \text{ N/C}$



Lesson 7 – Electric Potential

Comparisons Between Fields

In our discussion of electric forces and electric fields, it is important to draw parallels between these topics and those associated with gravity. There are many similarities. In this lesson, we will turn our attention to the energy associated with electric forces and fields, and as we will observe, this is another similarity between gravity and electricity.

Recall that forces acting at a distance do work on objects and can transfer energy to them. Think of the force of gravity as an example – the potential energy associated with an object of mass m at a height h above the Earth's surface is expressed as mgh .

The electric force is no different – given an object's initial position in an electric field, we can determine the amount of energy required to move it to some final location.

Gravity	Electricity

Electric Potential Energy

With two point charges q_1 and q_2 , the electric potential energy stored in the field will change depending on the signs of the charges. Energy is not a vector, but a scalar, and so the sign of energy tells us how much work can be done. The derivation of electric potential energy depends on the electric force and although we will not derive the expression, it is given as

$$E_e = \frac{kq_1q_2}{r}$$

If q_1 and q_2 are opposite, they attract and $E_e < 0$.

If q_1 and q_2 are the same, they repel and $E_e > 0$.

Electric Potential

Although it sounds similar, electric potential is *not* the same as electric potential energy. In much the same way as an electric field differs from an electric force, so the potential differs from potential energy.

The **electric potential**, V , at any given point in an electric field is the electric potential energy of a point charge divided by the magnitude of the charge. Mathematically:

$$V = \frac{E_e}{q}$$

Theoretically, V represents the amount of work it takes to move a positive test charge from rest at an infinite distance to a specific point in the field of q_1 .

For a point charge, we can determine an expression for the potential:

The units of potential are **volts**. One volt is the electric potential at a point in the electric field if 1 J of work is required to move 1C of charge from infinity to that point. $1V = 1 \text{ J/C}$.

Example 1

Calculate the electric potential a distance of 0.40 m from a point charge of $6.4 \times 10^{-6} \text{ C}$.

Potential Difference

The potential difference between any two points A and B in an electric field is defined as the change in potential energy of the system divided by the test charge.

Example 2

How much energy is required to increase the potential of a charge of $3.0 \times 10^{-7} \text{ C}$ by 120 V?

Example 3

A positive test charge of $1.5 \times 10^{-6} \text{ C}$ is placed in an electric field 10 cm from another charge of magnitude $-5.0 \times 10^{-6} \text{ C}$ that is anchored in place. What is the potential difference between the test charge's initial position and a point 5.0 cm closer to the negative charge?

Lesson 8 – Motion of Charged Particles in an E Field

Now that we are aware of the function of electric fields and the potential energy associated with them we can turn our attention to the description of the motion of a charged particle in an electric field.

Thought Experiment

Let's consider a small test charge q_t with a mass m tiny enough that we can ignore the effect of gravity. Placed in a vacuum, the charge experiences an electric field from another charge $+q$ when fixed in place a distance r away.

From Coulomb's Law, we know that $F_e = \frac{kq_1q_2}{r^2}$. This means, then, that Newton's second law gives the acceleration of particle 1,

$$a = \frac{F_e}{m}$$

We would like to be able to describe the motion of the particle, but we have encountered a problem.

As the particle begins to move, F_e changes. We obtain a non-uniform acceleration and our equations derived for kinematics are useless. We turn our attention to energy in order to obtain a solution for the motion of the particle.

As q_t and $+q$ separate, the electric potential energy E_e decreases and q_t gains kinetic energy. The conservation of energy tells us that the decrease in potential energy must equal the increase in kinetic energy.

$$-\Delta E_e = \Delta E_k$$

And so for these two point charges,

Example 1

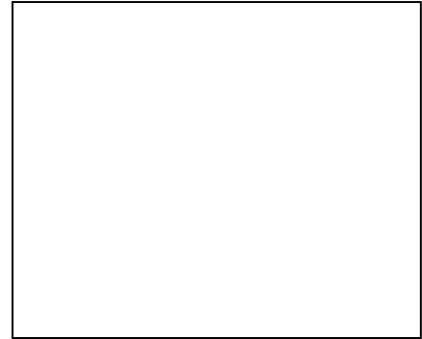
A small pith ball of mass 1.0×10^{-5} kg and charge 2.0×10^{-9} C is at rest 25 cm from a fixed charge of 5.0×10^{-6} C. Neglecting gravitational effects and air resistance, how fast will the pith ball be moving when it is 50 cm from the other charge?

Other Charge Distributions

The above discussion is perfect if and only if a point charge (or collection of point charges) creates the electric field. We need to be cautious, because this is only one type of electric field. Consider that we have solved for electric fields from a number of different charge distributions using Coulomb's Law.

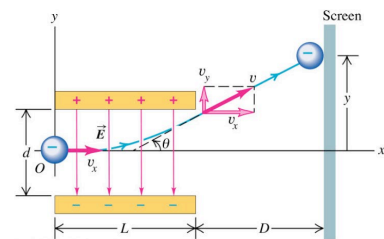
Uniform Electric Fields

One specific type of electric field that is different from that of a point charge is especially useful. It is the uniform field created between two plates of opposite charge. Recall from lesson 3 in this unit that it has the following appearance:



When the test charge q_t travels through a uniform electric field, the particle moves with uniform acceleration and we can use our standard equations of motion.

In the diagram to the right, an electron moves through a *uniform* electric field from two parallel plates. The path of the electron bends as it is attracted to the positively charged plate.



Example 2

The potential difference between two parallel plates is 8000 V. If a free electron is released at the negative plate with what speed will it hit the positive plate?

Millikan's Oil Drop Experiment

Early researchers of electricity like Benjamin Franklin and Coulomb knew that objects obtained their charge by transferring particles to other objects. Franklin thought that electricity was the flow of positive charge. And the coulomb was the first unit of charge assigned to represent a reproducible amount of charge.

But no one really knew that it was a certain amount of electrons that made up a coulomb – they didn't even know the charge of an electron. Until Robert Millikan performed his now famous oil drop experiment.

His experiment consisted of two parts:



He used an apparatus similar to the one shown below:

And then by balancing forces was able to mathematically determine the charge on one oil droplet.

He then performed a statistical analysis on a series of measurements and looked for the smallest charge he found. He theorized that all the other charges he found were integral multiples of this one small value.

$$e = 1.602 \times 10^{-19} \text{ C}$$

Lesson 9 – Magnetic Theory & Magnetic Fields

This lesson will involve the introduction and review of magnetic theory and introduce the origin of magnetic fields.

Magnetic fields are similar to gravitational and electric fields in that they act at a distance. All force fields have two objects in common: something that creates the field, and something that responds to the field.

Magnetic character is not fully understood but is attributed to many small regions within an object called **domains**.

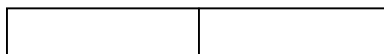
Domain Theory: All large magnets are made up of many magnetic regions called *domains*. The magnetic character of domains comes from the presence of even smaller unit magnets called *dipoles*. Dipoles interact with their neighboring dipoles. If they align with all the poles in one direction, then a larger **magnetic domain** is produced.

The Law of Magnetic Forces

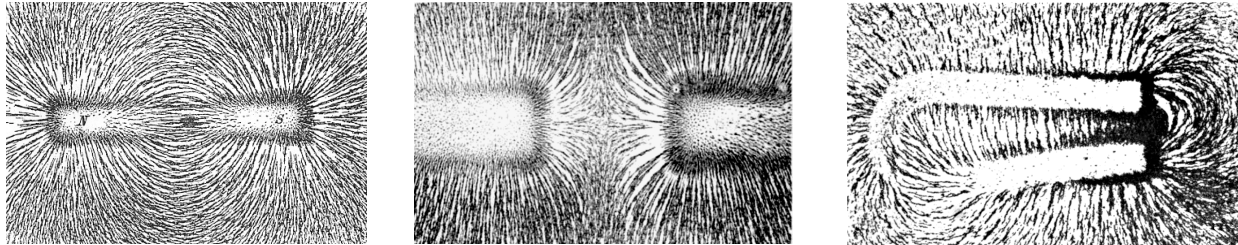
Similar magnetic poles *repel* one another with a force, even at a distance apart.

Dissimilar magnetic poles *attract* one another with a force, even at a distance apart.

Magnetic field lines, as with electric and gravitational field lines, can be mapped and drawn. To map electric field lines, positive test charges were always considered. With magnets, we use a compass to map the field lines. A compass is nothing more than a small magnetic dipole that is free to spin.



Often, magnetic field lines can be observed using iron filings. Iron filings, ferromagnetic in character, are like millions of tiny compasses. By convention, field lines always flow from north to south.

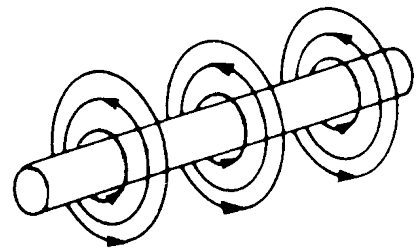


Electromagnetism

For many years scientists struggled to link the forces between electricity and magnetism. Hans Christian Oersted discovered the relationship by accident while giving a lecture at the University of Copenhagen.

Oersted's Principle: The Magnetic Field around a Straight Conductor

This discovery leads us to realize that charge moving through a conductor generates a magnetic field. Oersted went on to develop a series of hand signals to help predict the direction of magnetic fields and forces.



Right-hand Rule #1 –

Right-hand Rule #2 –

Magnetic Dipoles

The above has lead scientists to theorize about the origin of magnetic dipoles. We have talked about domains and dipoles, but haven't mentioned their source.

- Electrons have spin.
- When they spin, they give rise to a changing electric field also known as an electron current.
- An electron can spin in only one of two directions; \uparrow or \downarrow
- Unpaired electrons create a magnetic field causing the atom to become a dipole.
- Materials with unpaired electrons (which exhibit a magnetic field) are called **paramagnetic**.
- Materials with electron pairs are described as **diamagnetic** and have no measurable magnetic field because the electron spins cancel each other out.

The Magnetic Field

Recall that the area surrounding any stationary or moving charge has an associated electric field. We can quantify the electric field for point charges and a few other specific geometries. **Magnetic fields**, however, exist only in the region of space surrounding a magnetic material or a *moving* electric charge.

Historically the symbol \vec{B} has been used to represent the magnetic field. Experiments on various charged particles moving in a magnetic field have given us the following results:

- ✓ The magnitude of the magnetic force \vec{F}_b is proportional to the charge q and the speed v of the particle.
- ✓ The magnitude and direction of \vec{F}_b depend on the velocity of the particle and the magnitude and direction of the magnetic field.
- ✓ When a charged particle moves parallel to the magnetic field, \vec{F}_b is zero.
- ✓ \vec{F}_b is always perpendicular to both \vec{v} and \vec{B} .

The result of the above observations is a cross product relationship given by



The magnetic field is measured in units of tesla (T) where

$$1\text{T} = \frac{\text{N}}{\text{C} \cdot \text{m/s}}$$

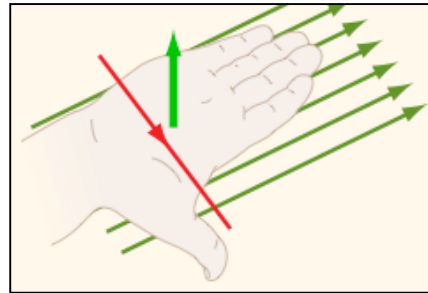
Magnetic Force on a Current Carrying Conductor

The above expression was formulated for a point charge moving through a magnetic field. It shouldn't come as a surprise that if you put a wire carrying a current of charge (many charges moving with a speed) it too would experience a force.

$$\vec{F}_b = I\vec{L} \times \vec{B}$$

$$|\vec{F}_b| = ILB \sin \theta$$

Right-hand Rule #3 –



Example 1

A wire carrying a current of 10.0 A is suspended between a house and its garage 5i m away. If the Earth's magnetic field is straight down ($-j$) and has a value of 5.0×10^{-5} T, what is the magnitude and direction of the force on the wire?

Sources of Magnetic Fields

We have looked at the magnetic force acting on moving point charges and current-carrying conductors. And we know that moving charges create magnetic fields. But we would like to take a look at what factors affect the strength of the magnetic field in the space around a conductor.

While it is true that determining the magnetic field strength for different *general* configurations requires some heavy-duty calculus, we actually don't need to concern ourselves with the details if we only pay attention to some specific configurations where the calculus is done for us.

There are three geometries we need to know: a long, straight wire, a flat loop and a solenoid.

The Infinite Wire:

The Flat Loop:

The Solenoid:

Example 2

A long straight conductor is coiled once into a flat loop of radius 3.0 cm. If the wire carries a current of 1.0 A, find the magnetic field at the centre of the loop.

Example 3

Find the magnetic force on a wire carrying a 3.0 A current, from a second wire carrying a current of 9.5 A at a distance of 1.4 cm.

Lesson 10 – Applications of Magnetic Fields

Last day we started the lesson by finding the force on a charged particle in a uniform magnetic field. We found the result to be:

$$\vec{F}_b = q\vec{v} \times \vec{B}$$

The magnitude of the force is $F = qvB \sin \theta$ and the direction is given by RHR #3. Lets consider a positive particle moving with a *constant* speed in a uniform magnetic field.

We can see that the magnetic field changes the direction of the velocity because the magnetic force always points perpendicular to both the velocity and the field. The path is circular and is a perfect example of uniform circular motion.

Using this equation, we can see that if the charge and velocity of the particle are kept constant in the magnetic field a tiny change in mass will affect the radius of the circular path.

J. J. Thompson developed a way to keep the velocity constant allowing him to measure the associated radius and ultimately find a value for the mass of an electron. Here is how he did it:



He balanced the electric force from the parallel plates and magnetic force from the coil to obtain a constant velocity.

And was able to find the charge to mass ratio for an electron:

Millikan had discovered the charge of an electron and Thompson used this to discover m_e ,

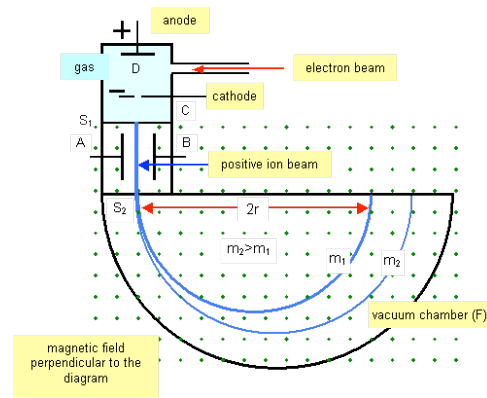
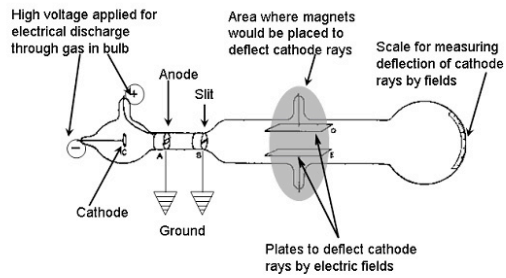
Mass Spectrometer

Thompson's method gained popularity and was adapted to measure almost any charged particle in a device known as a mass spectrometer. In this device, particles are ionized, accelerated and then injected into a uniform magnetic field. The radius of the particles' circular path reveals their mass.

Using electric, magnetic and centripetal force, we can find an equation:

$$m = \frac{qB^2r^2}{2V}$$

Where m is the mass of the particle (kg), B is the magnetic field (T), r is the radius (m), and V is the potential difference (V).

Example 1

A charged particle enters a uniform magnetic field of strength 3.2×10^{-2} T at a speed of 6.0×10^6 m/s. When the charge enters the field perpendicular to the field lines, it traces a circular path of radius 0.018 m. What is the charge-to-mass ratio for the particle?

Example 2

A single ionized $^{239}_{94}\text{Pu}$ ion of mass 4.0×10^{-25} kg is accelerated through a potential difference of 1.0×10^5 V. Find the maximum speed of the ion and the radius of its path in a uniform magnetic field of strength 0.12 T.

Lesson 11 – Electromagnetic Induction

Oersted found that moving charges create magnetic fields. In 1831, Michael Faraday discovered a concept that complemented Oersted's principle and completed or solidified our understanding that electricity and magnetism are linked in theory and practice.

Faraday's Law of Electromagnetic Induction

Faraday was able to show that a changing magnetic field created a rise in current flow. A simple demonstration shows this to be true:

By coiling a conductor into a solenoid, more current can be produced – a solenoid with a few turns does not register as much current as a solenoid with many turns. But the question still remained, what determines the direction of current flow?

German physicist Heinrich Lenz was able to answer this question by considering the conservation of energy and applying it to electromagnetic induction. He postulated that the electrical energy induced in the conductor must come from the kinetic energy of the moving magnetic field.

The *increase* in the *electric potential energy* of the *charges* in the induced current results in a *decrease* in the *kinetic energy* of the *moving magnetic field*. The loss in kinetic energy is felt as an *opposition* to the moving field. Lenz reasoned that the opposition to the motion is from an induced magnetic field created by the charge flow.



Lenz's Law

This allows us to determine the direction of current flow by determining the direction of the induced magnetic field using right-hand rule #2.

Example 1

Use Lenz's law to determine the direction of the induced conventional current flow in the coils seen below.

