Conceptual Physics
Sound Waves
Electricity and Magnetism

Lana Sheridan

De Anza College

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Last time

- heat engines
- waves
- oscillations
- interference
- standing waves

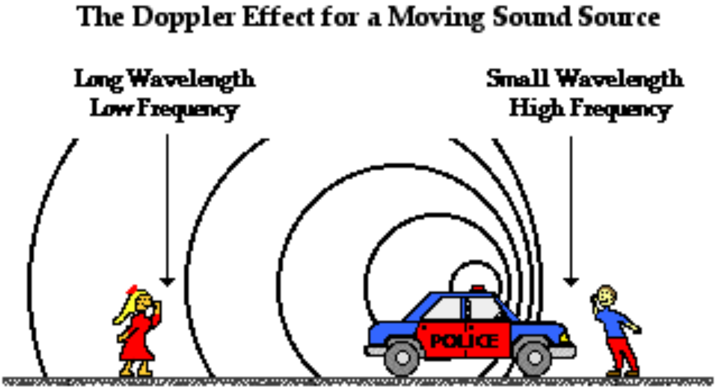
Overview

- Doppler effect
- bow waves
- sound
- electric charge
- electric field

The Doppler Effect

Waves from approaching sources seem to have higher frequency than waves from stationary sources.

Waves from receding sources seem to have lower frequency than waves from stationary sources.



The Doppler Effect

How much does the frequency change?

$$f_D = \frac{v}{v + v_s} f_s$$

where v is the speed of the wave, f_s is the frequency emitted by the source, and f_D is the frequency detected by a stationary detector.

v_s is the speed of the wave source: here we use the convention that v_s is *negative* if the source is approaching us and *positive* if it is moving away from us.

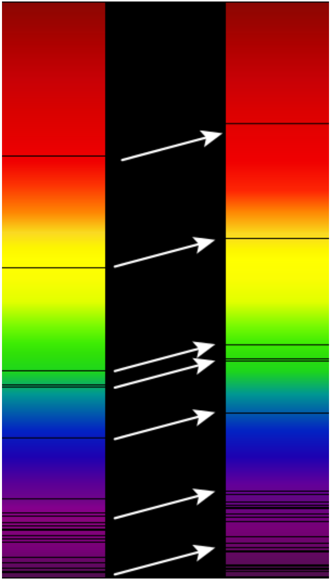
The Doppler Effect Question

A police car has a siren tone with a frequency at 2.0 kHz.

It is approaching you at 28 m/s. What frequency do you hear the siren tone as?

Now it has passed by and is moving away from you. What frequency do you hear the siren tone as now?

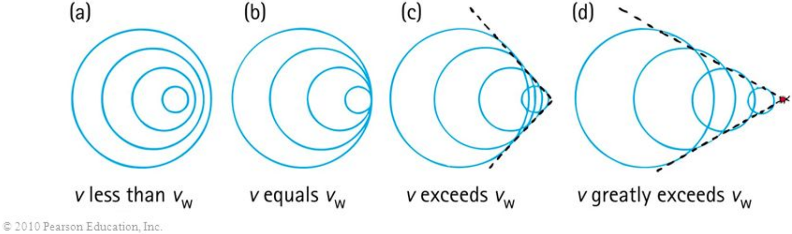
The Doppler Effect and Astronomy



[1] Image from Wikipedia by Georg Wiora.

Bow Waves and Shock Waves

Bow waves and shock waves can be detected by nearby observers when the speed of the wave source exceeds the speed of the waves.



This effect happens when an aircraft transitions from subsonic flight to supersonic flight.

[1]Figure from Hewitt, 11ed.

Bow waves

Supersonic transition

Sound

Sound is a longitudinal wave, formed of pressure fluctuations in air.

At sea level at 20°C, sound travels at 343 m/s.

All sound waves will travel at this speed relative to the rest frame of the air.

$$v = f\lambda$$

A low frequency means a longer wavelength.

[1] In higher layers, the speed of sound varies with the temperature.

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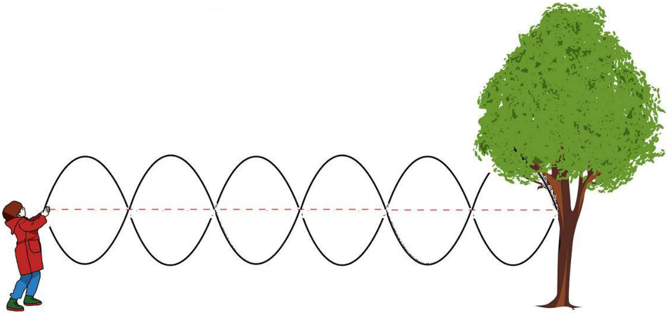
Sound can travel at different speeds in other materials. It travels faster in water, and slower at higher altitudes in the atmosphere (troposphere layer).[1]

[1] In higher layers, the speed of sound varies with the temperature.

Standing Waves and Resonance

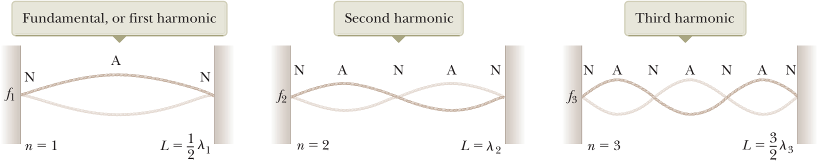


Standing wave motions are called **normal modes**.

normal mode

A pattern of motion in a physical system where all parts of the system move sinusoidally with the same frequency and with a fixed phase relation.

Standing Waves and Resonance on a String



The **natural frequencies** of a string are given by:

$$f_n = \frac{nv}{2L}$$

where n is a positive natural number, L is the length of the string, and v is the speed of the wave on the string.

A long string has a low fundamental frequency.

A short string has a high fundamental frequency.

Standing Waves and Resonance on a String

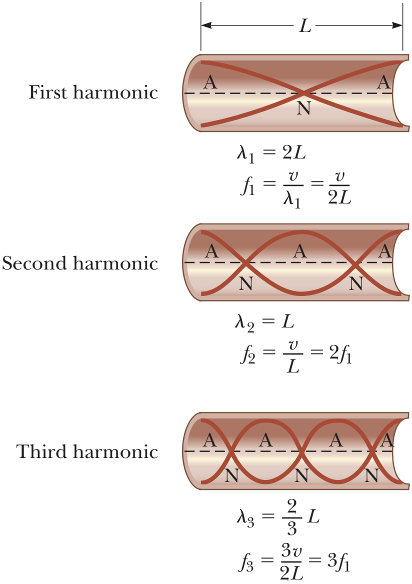
When a string is plucked, resonant (natural) frequencies tend to persist, while other waves at other frequencies are quickly dissipated.

Stringed instruments like guitars can be tuned by adjusting the tension in the strings.

Changing the tension changes the speed of the wave on the string. That changes the natural frequencies.

While playing, pressing a string against a particular fret will change the string length, which also changes the natural frequencies.

Standing Sound Waves in air columns



Standing sound waves can be set up in hollow tubes.

This is the idea behind how pipe organs, clarinets, didgeridoos, *etc.* work.

[1]Figure from Serway & Jewett, page 547.

Musical Instruments

Didgeridoo:

Longer didgeridoos have lower pitch, but tubes that flare outward have higher pitches this can also change the spacing of the resonant frequencies.

[1] Matt Roberts via Getty Images.

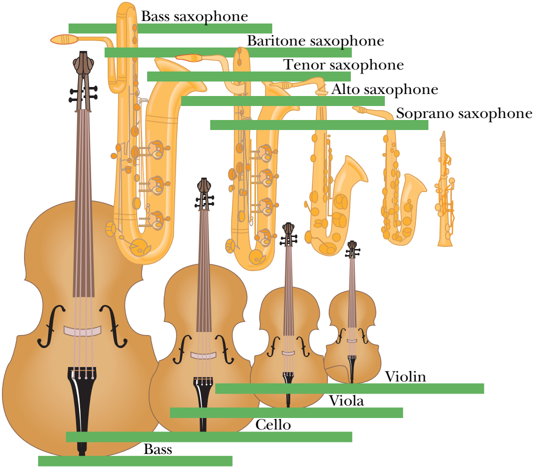
Musical Instruments, Pipe Organ

The longest pipes made for organs are open-ended 64-foot stops (tube is effectively 64 feet+ long). There are two of them in the world. The fundamental frequency associated with such a pipe is 8 Hz.

32' stops give 16 Hz sound, 16' stops give 32 Hz, 8' stops give 64 Hz, *etc*.

[1]Picture of Sydney Town Hall Grand Organ from Wikipedia, user Jason7825.

Musical Instruments



In general, larger instruments can create lower tones, whether string instruments or tube instruments.

[1] Halliday, Resnick, Walker, 9th ed, page 458.

Decibels: Scale for Sound Level

The ear can detect very quiet sounds, but also can hear very loud sounds without damage. (Very, very loud sounds do damage ears.)

As sound wave that has twice the energy does not “sound like” it is twice as loud.

Many human senses register to us on a logarithmic scale.

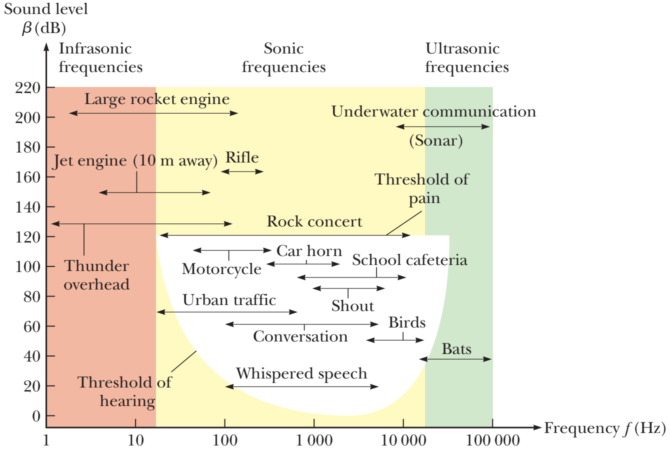
Decibels (dB) is the scale unit we use to measure loudness / sound level.

Roughly, a noise sounds twice as loud if its sound level is increased by 10 dB, or it has **10 times the energy**.

Perception of Loudness and Frequency

Human hearing also depends on frequency.

Humans can only hear sound in the range 20-20,000 Hz.



Low frequency sounds need to be louder to be heard.

[1]Figure from R. L. Reese, University Physics, via Serway & Jewett.

Sound

Sound waves can cause resonant vibrations in objects that will oscillate with the same frequency.

(Tuning forks!)

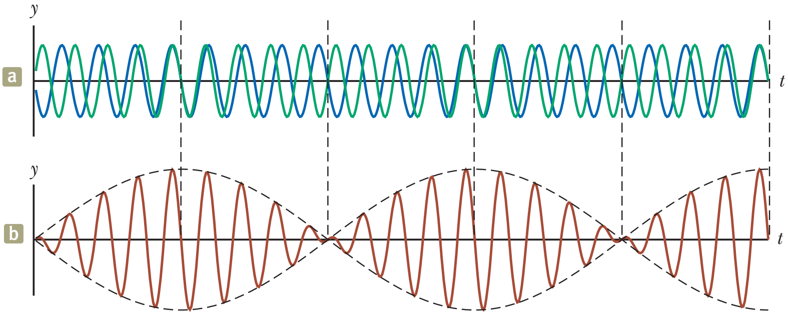
Sound waves can also interfere just like other waves.

Beats

Two sound waves with slightly different frequencies interfere to form **beats**.

These are louder and quieter variations in sound level.

Amplitude vs t at a fixed position:



Beats

Thus the frequency of the beats is

$$f_{\text{beat}} = |f_1 - f_2|$$

If f_1 and f_2 are similar the beat frequency is much smaller than either f_1 or f_2.

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Humans cannot hear beats if $f_{\text{beat}} \gtrsim 30$ Hz.

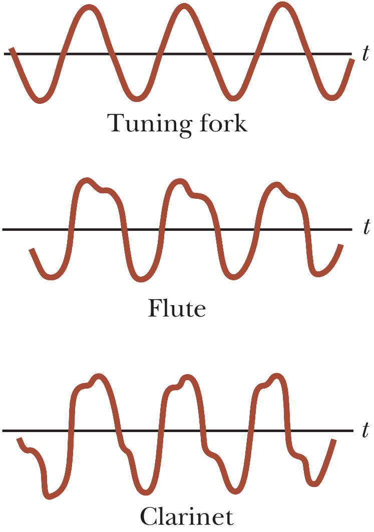
If the two frequencies are very different we hear a chord.

If the two frequencies are very close, we hear periodic variations in the sound level.

This is used to tune musical instruments. When instruments are coming into tune with each other the beats get less and less frequent, and vanish entirely when they are perfectly in tune.

More complex sounds

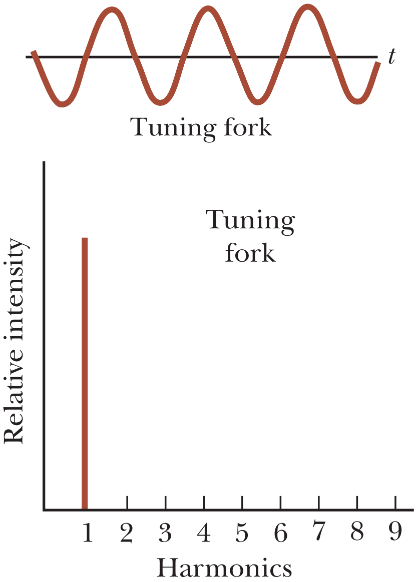
Different musical instruments make different waveform patterns.



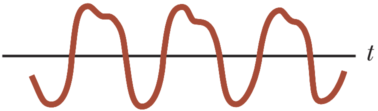
For example this is why a flute and a clarinet playing the same note still sound a bit different.

More than one frequency is sounded.

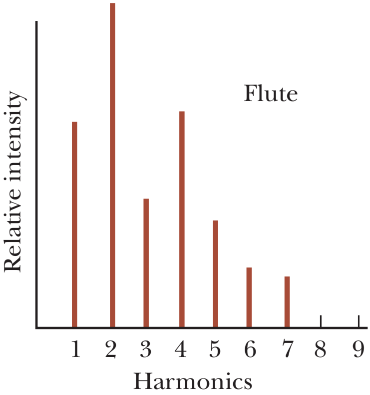
More complex sounds



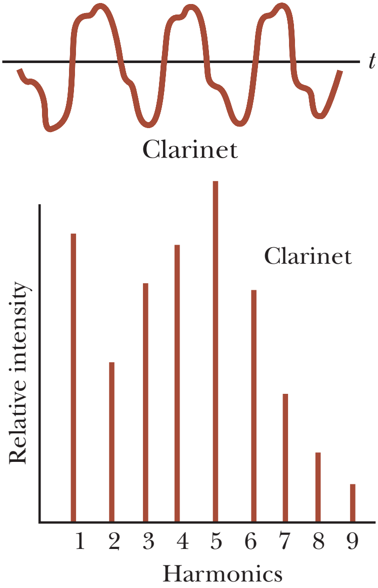
More complex sounds



Flute

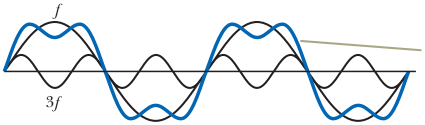


More complex sounds

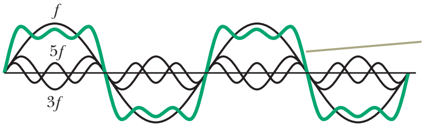


Example: Square Wave

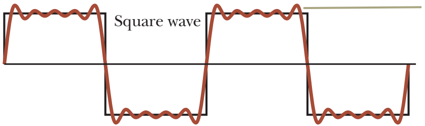
Two frequencies f and $3f$.



Three frequencies, f, $3f$, and $5f$.



Frequencies up to $9f$.



Electric Charge

Charge is an intrinsic (essential) property of subatomic particles.

Examples of charged particles:

- protons (positively charged)
- electrons (negatively charged)

Static electric charge can be experienced on a large scale through static electricity.

Electrostatic force

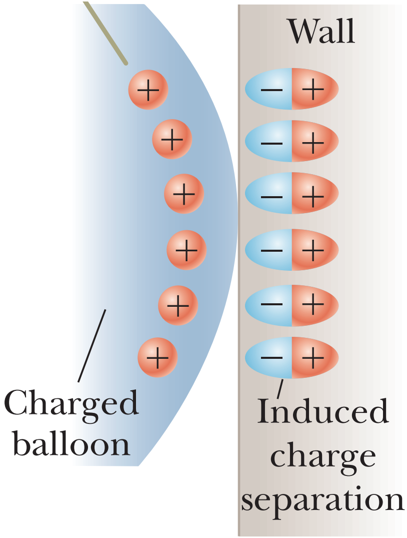
Charged objects exert a force (the electrostatic force) on one another.

Charges with the **same** electrical sign **repel** each other.

Charges with **opposite** electrical signs **attract** each other.

The unit for charge is the Coulomb, written with the symbol C.

Induced Charge Polarization



Conductors and Insulators

Some materials allow charges to flow through them easily, some do not.

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Conductors

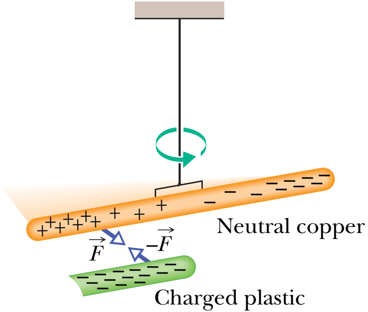
materials through which charge can move readily

Insulators

(also called nonconductors) are materials that charge cannot move through freely

Induced Charge

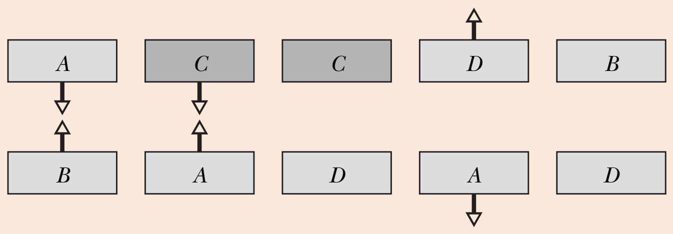
If a conductor is brought close to a charged object, positive and negative charges in the conductor start to separate and we say a charge is **induced** on the conductor.



Overall, the conductor is neutral, but it is still attracted to the charged object.

Question

A, *B*, and *D* are charged pieces of plastic. *C* is an electrically neutral copper plate.



Plates *C* and *D*

(A) attract each other

(B) repel each other

[1] Page 564, Halliday, Resnick, Walker, 9th ed.

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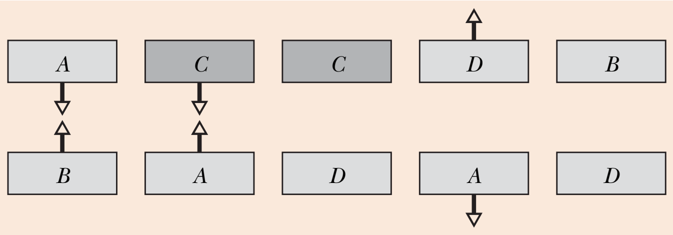

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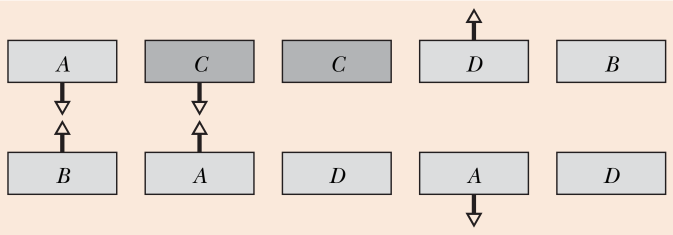

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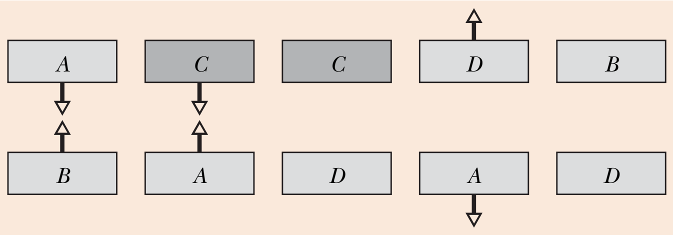

Plates *B* and *D*

(A) attract each other ←

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Electrostatic Forces

For a pair of point-particles with charges q_1 and q_2, the magnitude of the force on each particle is given by **Coulomb's Law**:

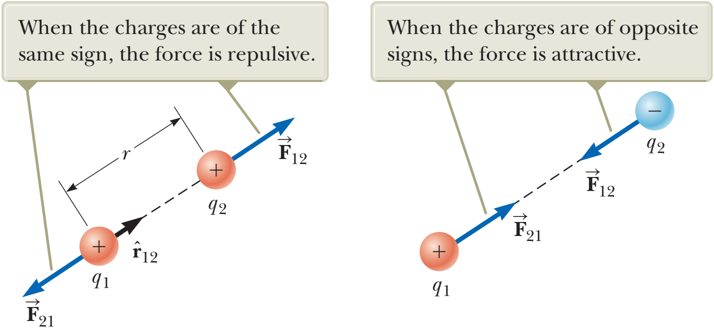
$$F_{1,2} = \frac{k\, q_1 q_2}{r^2}$$

k is the electrostatic constant and r is the distance between the two charged particles.

$k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$

Coulomb's Law

$$\mathbf{F}_{1\to 2} = \frac{k\, q_1 q_2}{r^2}\,\hat{\mathbf{r}}_{1\to 2}$$



[1]Figure from Serway & Jewett, Physics for Scientists and Engineers, 9th ed.

Electrostatic Constant

The electrostatic constant is: $k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9$ N m^2 C^{-2}

ϵ_0 is called the **permittivity constant** or the **electrical permittivity of free space**.

$\epsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}

Conservation of Charge

Charge can move from one body to another but the net charge of an isolated system never changes.

This is called **charge conservation**.

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What other quantities are conserved?

Fields

Just as with gravity in Chapter 9:

field

A field is any kind of physical quantity that has values specified at every point in space and time.

In EM we have vector fields. The electrostatic force is mediated by a vector field.

vector field

A field is any kind of physical quantity that has values specified *as vectors* at every point in space and time.

Fields

A force-field can be used to figure out the interaction that particular particle will have with other objects in its environment.

Imagine a charge q_0. We want to know the **force** it would feel if we put it at a specific location.

Fields

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Imagine a charge q_0. We want to know the **force** it would feel if we put it at a specific location.

The electric field $\mathbf{E}$ at that point will tell us that!

$$\mathbf{F} = q_0 \mathbf{E}$$

Fields

The source of the field could be another charge.

We do not need a description of the sources of the field to describe what their effect is on our particle. All we need to know if the field!

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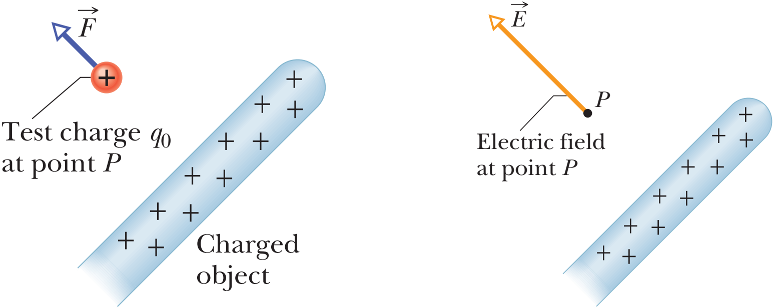
We do not need a description of the sources of the field to describe what their effect is on our particle. All we need to know if the field!

This is also true for gravity. We do not need the mass of the Earth to know something's weight:

$$\mathbf{F}_G = m_0\mathbf{g} \qquad \mathbf{F}_E = q_0\mathbf{E}$$

Force from a Field



$$\mathbf{F} = q_0 \mathbf{E}$$

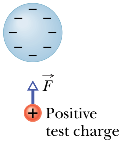
but also:

$$\mathbf{E} = \frac{\mathbf{F}}{q_0}$$

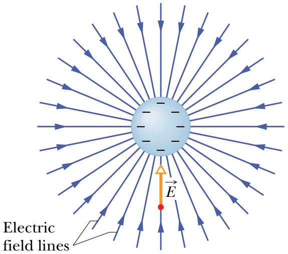
[1]Figure from Halliday, Resnick, Walker.

Field Lines

Fields are drawn with lines showing the direction of force that a test particle will feel at that point. The density of the lines at that point in the diagram indicates the approximate magnitude of the force at that point.



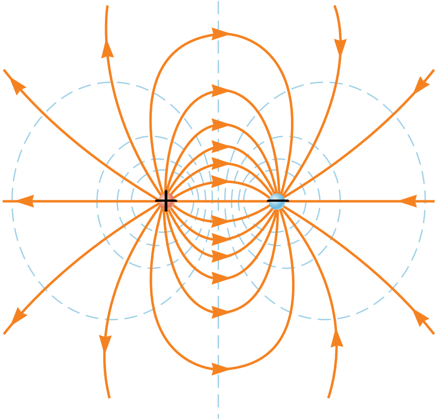
(a)



(b)

Field Lines

The electrostatic field caused by an electric dipole system looks something like:

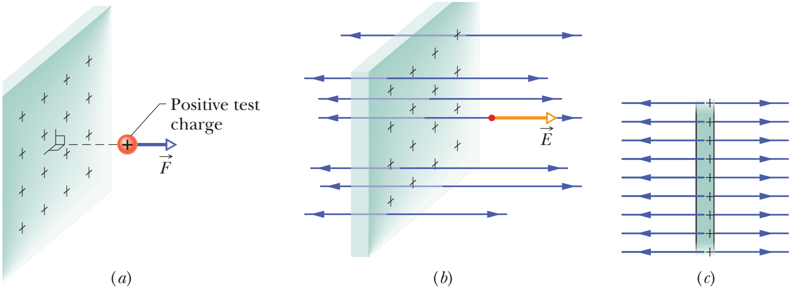


Notice that the lines point **outward** from a positive charge and **inward** toward a negative charge.

[1]Figure from Serway & Jewett

Field Lines

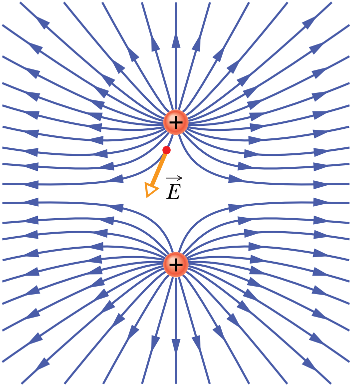
Imagine an infinite sheet of charge. The lines point **outward** from the positively charged sheet.

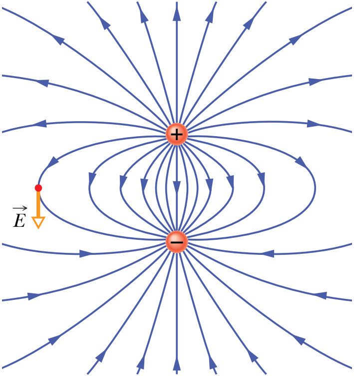


[1]Figure from Halliday, Resnick, Walker.

Field Lines

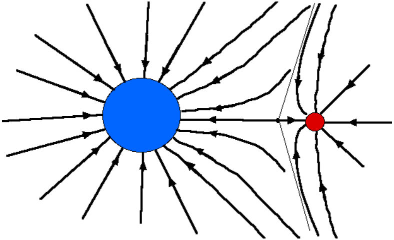
Compare the electrostatic fields for two like charges and two opposite charges:

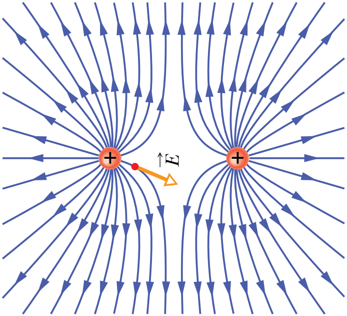




Field Lines

Compare the fields for gravity in an Earth-Sun system and electrostatic repulsion of two charges:

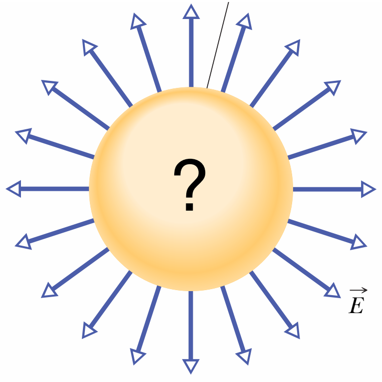




[1]Gravity figure from http://www.launc.tased.edu.au ; Charge from Halliday, Resnick, Walker

E-Field Question

Which of the following could be the charge on the particle hidden by the question mark?



(A) 0 C

(B) -1 C

(C) -1.6×10^{-19} C

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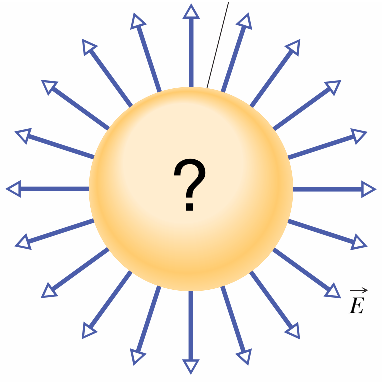

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Field from a Point Charge

Remember, if q_0 is a test charge, $\mathbf{E} = \frac{\mathbf{F}}{q_0}$.

We want an expression for the electric field from a point charge, q.

Using Coulomb's Law the force on the test particle is $\mathbf{F}_{\rightarrow 0} = \frac{k\,q q_0}{r^2}\hat{\mathbf{r}}$.

$$\mathbf{E} = \left(\frac{1}{q_0}\right)\frac{k\,q\,q_0}{r^2}\hat{\mathbf{r}}$$

The field at a displacement $\mathbf{r}$ from a charge q is:

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

Field from a Point Charge Example

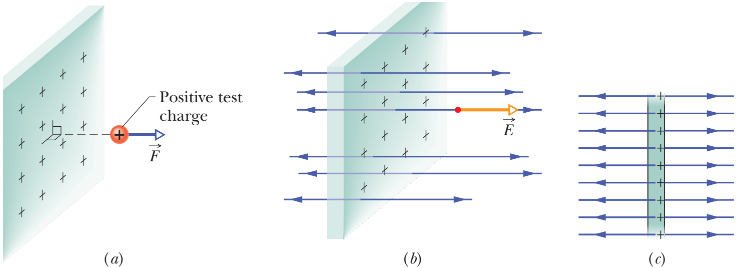
What is the magnitude of the electric field 1 cm from a $2\,\mu C$ charge?

Does the field point towards or away from the charge?

Electric field due to an Infinite Sheet of Charge

Consider an infinite sheet of charge.

The field from this sheet is uniform! It does not matter how far a point P is from the sheet, the field is the same.



Millikan's Oil Drop Experiment: Measuring e

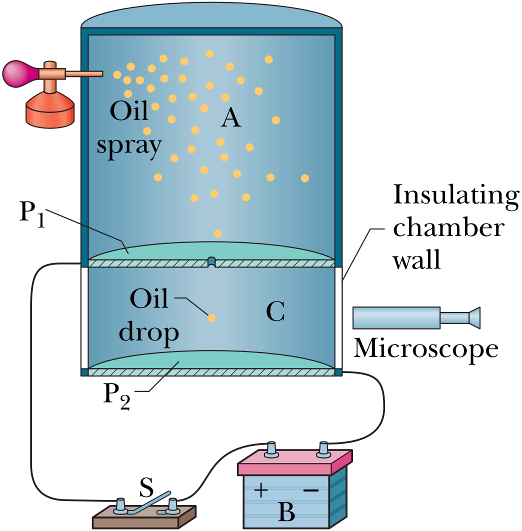
Units of field: N/C

Problem 10, page 403.

(a) If a drop of mass 1.1×10^{-14} kg remains stationary in an electric field of 1.68×10^{5} N/C, what is the charge on this drop?

(b) How many extra electrons are on this particular oil drop?

Millikan's Oil Drop Experiment: Measuring e



Summary

- Doppler effect
- bow waves
- sound
- electric charge
- electric field

Homework

- Prepare a 5-8 minute talk for next week. Tuesday, Aug 8.
- Essay question (Due tomorrow)
- Waves worksheet (Due Monday)
- 2 new worksheets: Coulomb's law & E-field (due Monday)

Hewitt,

- Ch 19, onward from page 347. Exercises: 35
- Ch 20, onward from page 365. Exercises: 1, 3; Problems: 1, 3, 7
- Ch 22, onward from page 403. Exercises: 3, 41; Problems: 1, 3