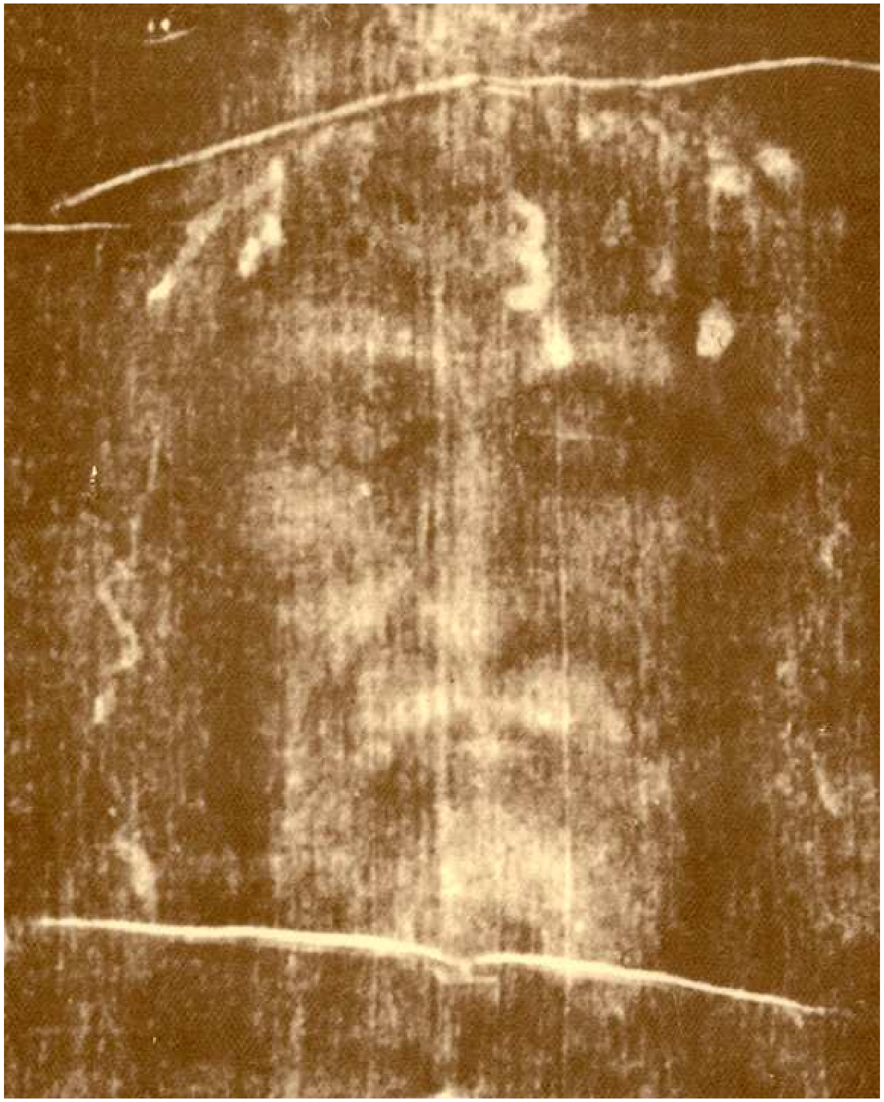
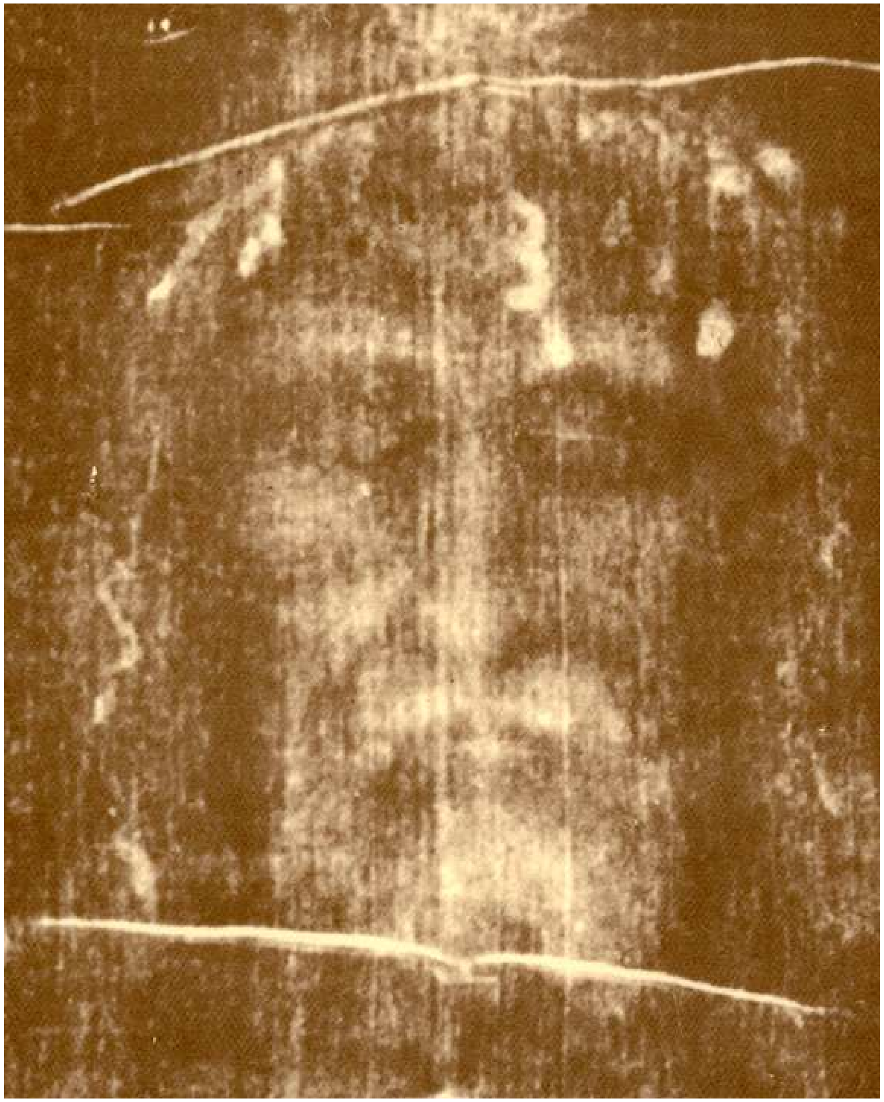
How Old is the Shroud of Turin and How Do We Know It?



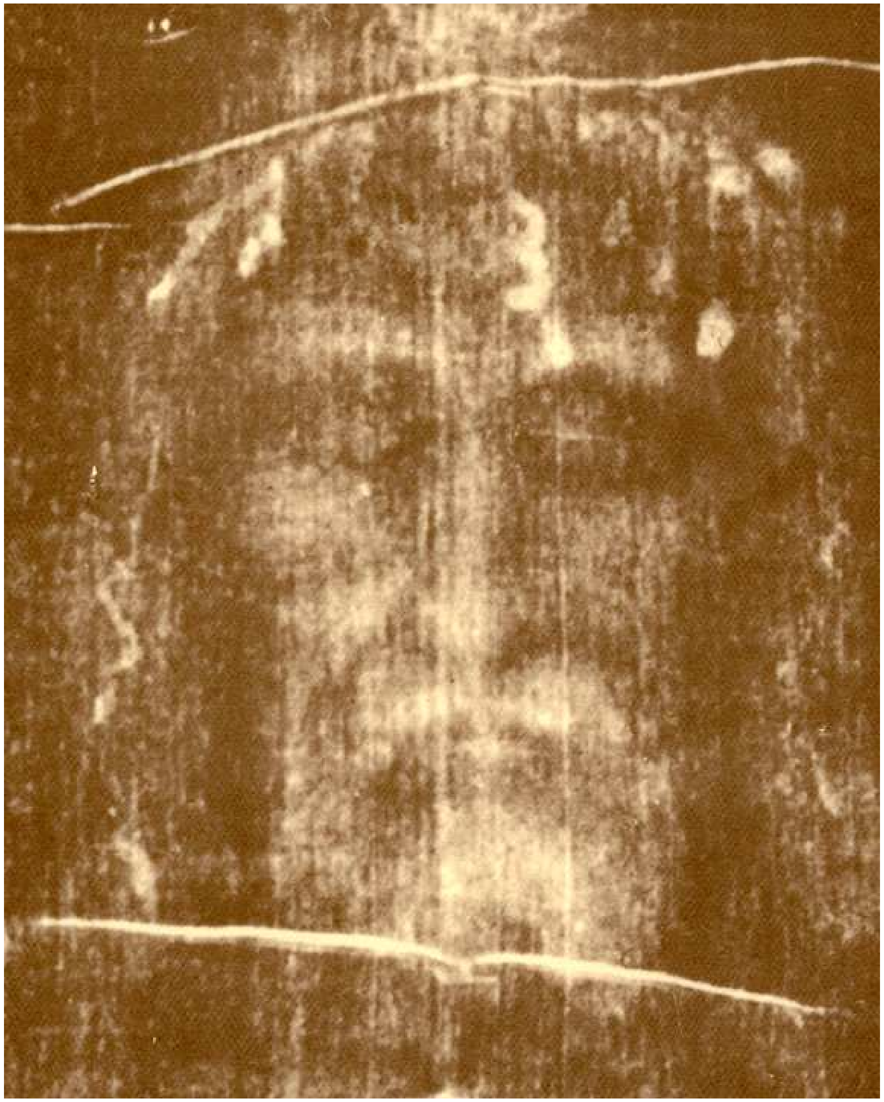
How Old is the Shroud of Turin and How Do We Know It?

- Radiocarbon Dating.

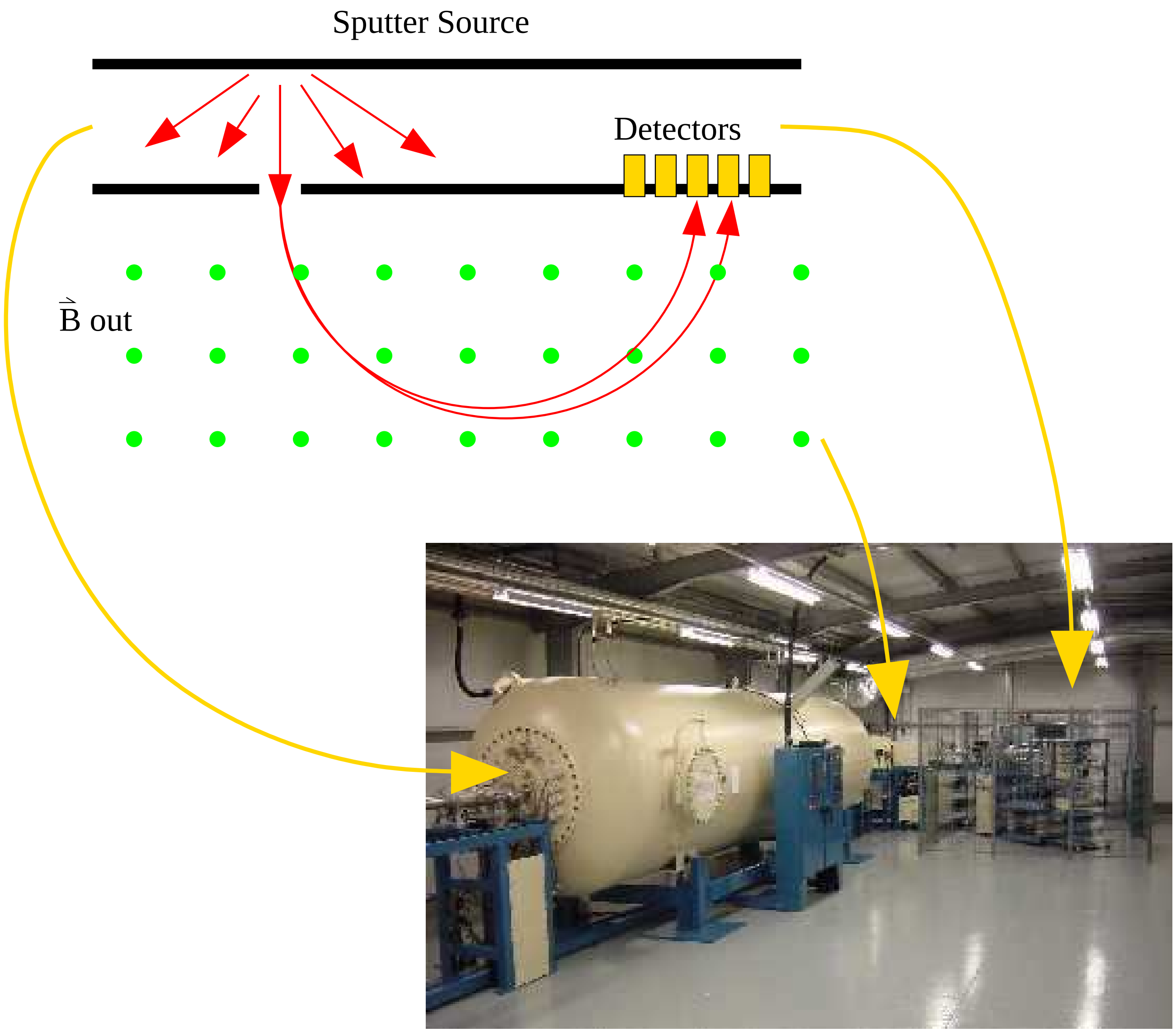


How Old is the Shroud of Turin and How Do We Know It?

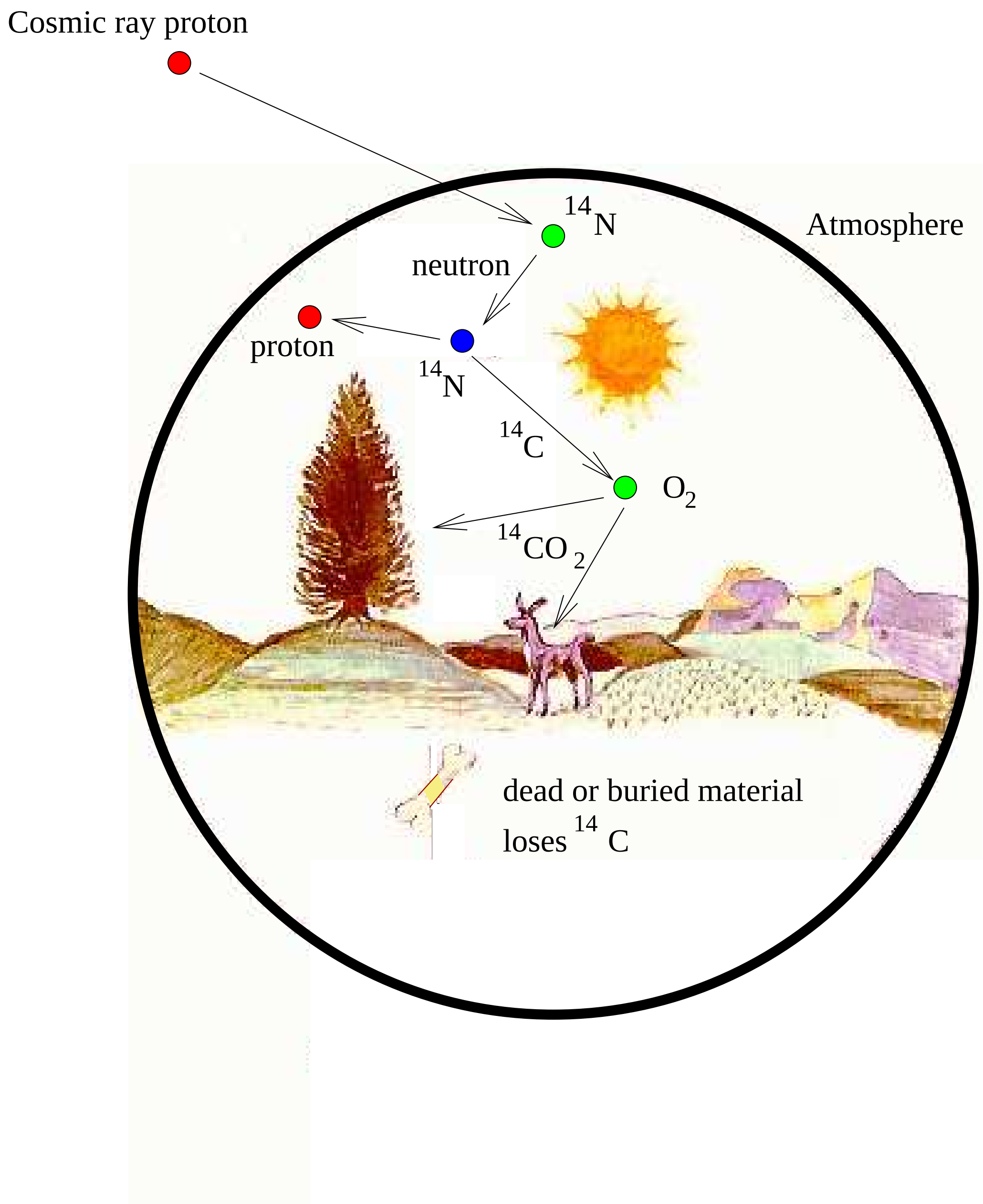
- Radiocarbon Dating.
- Mass Spectrometry



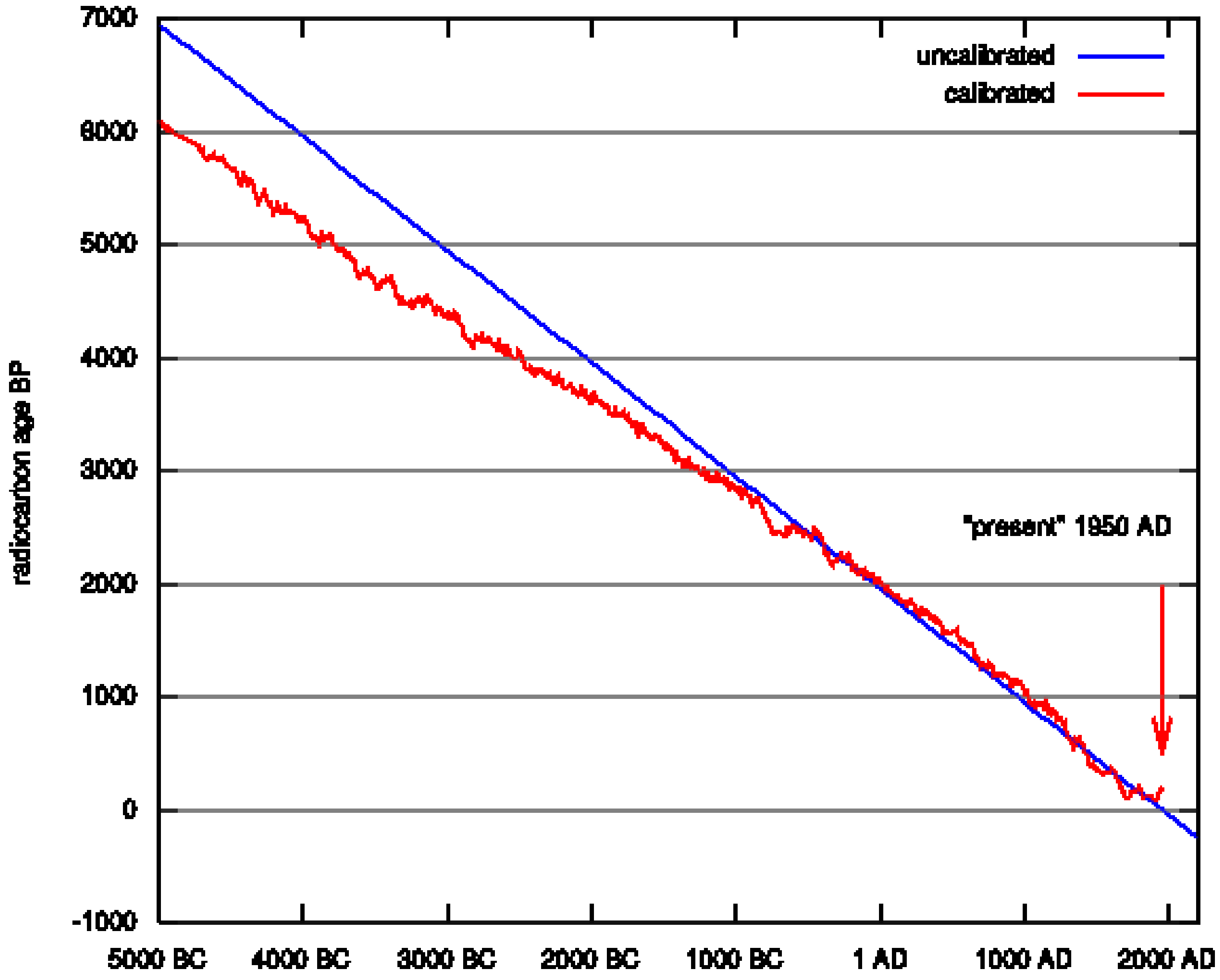
A Mass Spectrometer



Radiocarbon Dating



Radiocarbon Calibration Curve



The REAL Table of Elements

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor		Mass GeV/c^2	Electric charge
ν_e	electron neutrino	$<1\times10^{-8}$	0
e	electron	0.000511	–1
ν_μ	muon neutrino	<0.0002	0
μ	muon	0.106	–1
ν_τ	tau neutrino	<0.02	0
τ	tau	1.7771	–1

Quarks spin = 1/2

Flavor		Approx. Mass GeV/c^2	Electric charge
u	up	0.003	2/3
d	down	0.006	–1/3
c	charm	1.3	2/3
s	strange	0.1	–1/3
t	top	175	2/3
b	bottom	4.3	–1/3

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Comparing the Electrical and Gravitational Forces

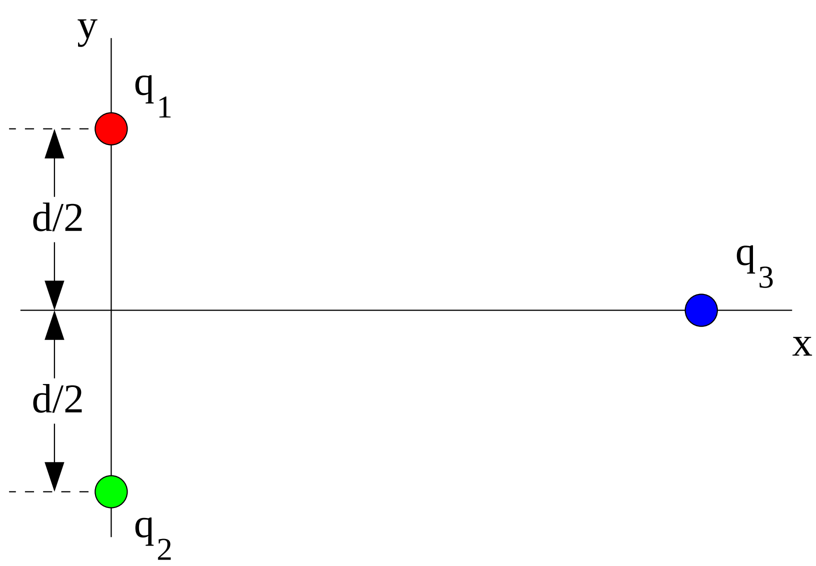
The electron and proton of a hydrogen atom are separated from each other by a distance $r = 5.2 \times 10^{-11}\ m$. What are the magnitudes and directions of the electrical and gravitational forces between the two particles? What is the centripetal acceleration of the electron? What is the period of the electron's orbit if it follows a circular orbit moving at constant speed?

$q = e = 1.6 \times 10^{-19}\ C$	$m_e = 9.11 \times 10^{-31}\ kg$
$k_e = 8.99 \times 10^{9}\ Nm^2/C^2$	$m_p = 1.67 \times 10^{27}\ kg$
$G = 6.67 \times 10^{-11}\ Nm^2/kg^2$	

The Electric Dipole

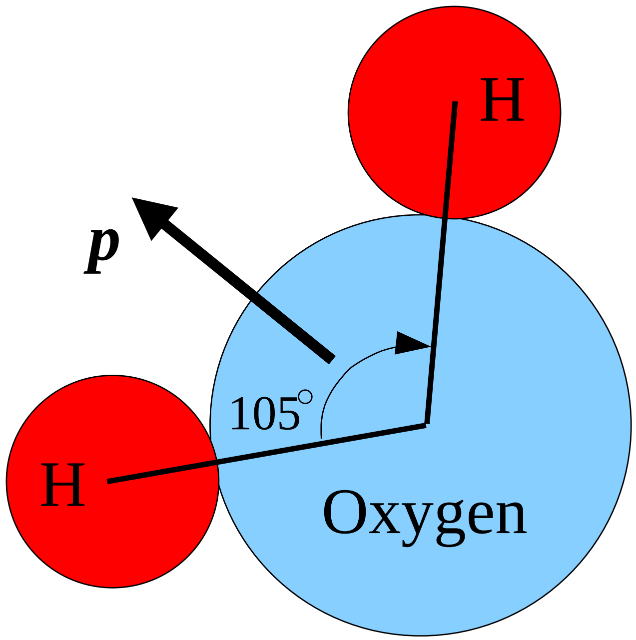
Consider the set of charges shown below. What is the force on charge 3 due to charges 1 and 2 given the conditions on the charges shown below? Express the answer in terms of q, x, and a. What is the electric field at the position of charge 3 due to the other charges?

$$q_1 = q > 0 \qquad q_2 = -q \qquad q_3 > 0$$



The Electric Dipole Moment of Water

The asymmetry of the water molecule leads to a dipole moment in the symmetry plane pointed toward the more positive hydrogen atoms. The measured magnitude of this dipole moment is $p = 6.2 \times 10^{-30} C - m$ where p is NOT the momentum, but defined as $p = qd$ where d is the separation between between two charges $+q$ and $-q$. Calculate the electric potential at any point along the axis defined by the dipole moment $\vec{p}$ in terms of q, d, and r the distance along the axis. Where are the equilibrium points?



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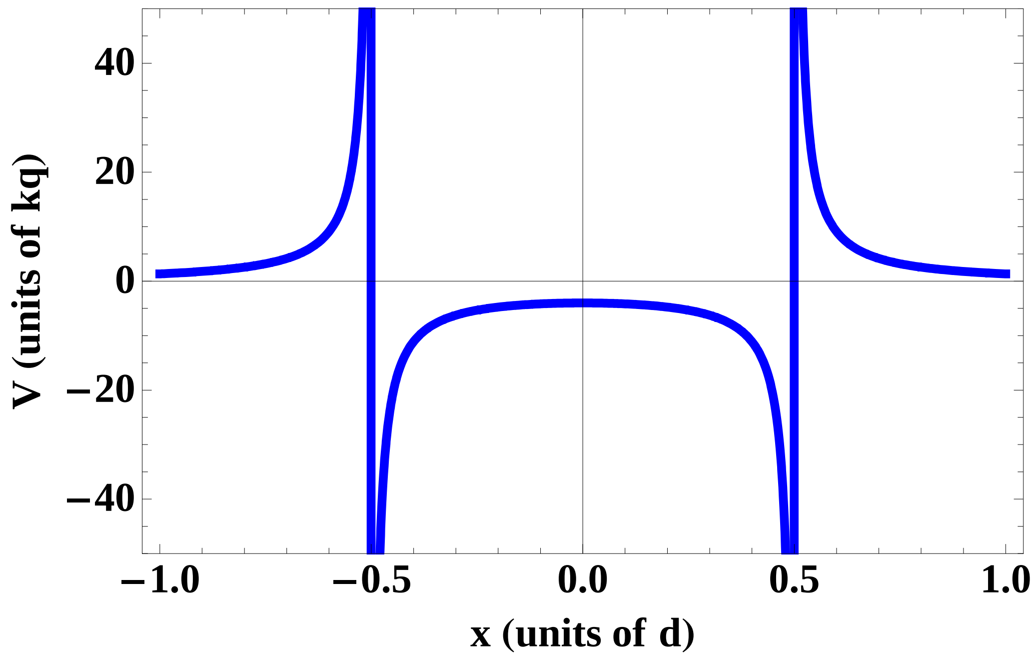

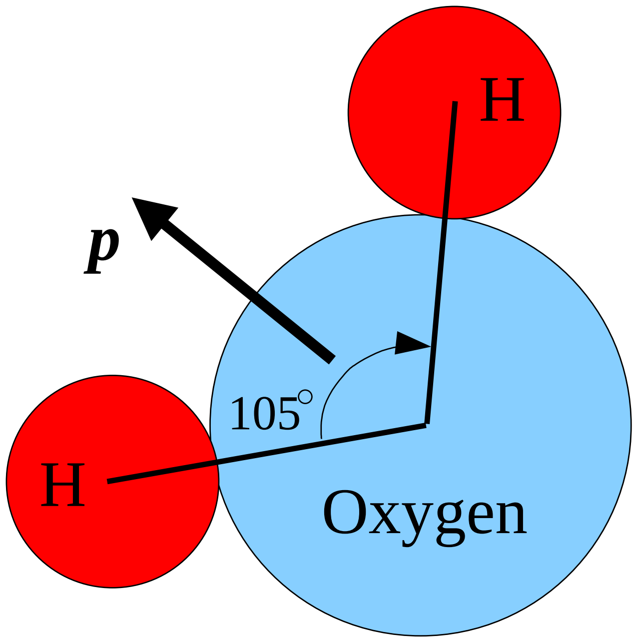

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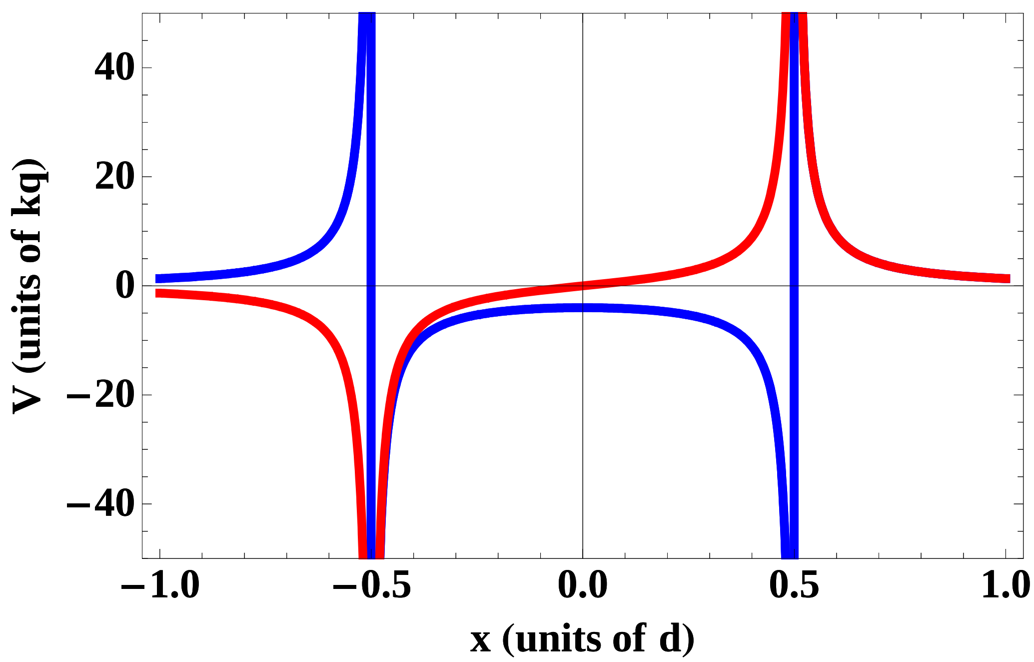

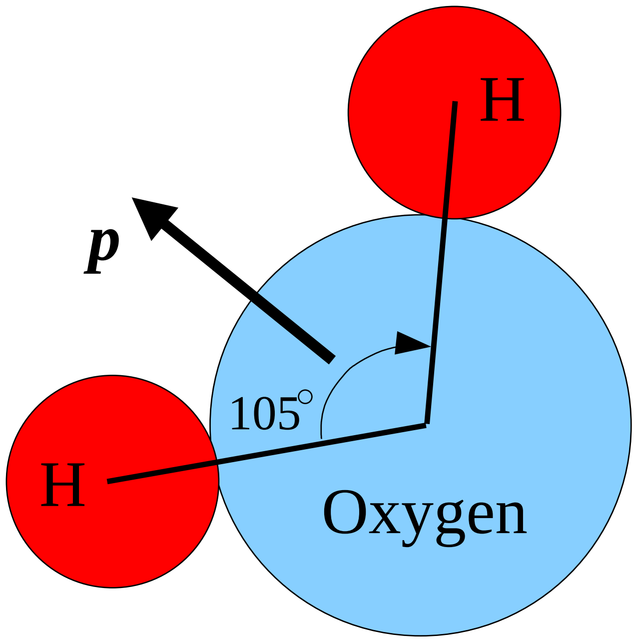

The Electric Dipole Moment of Water

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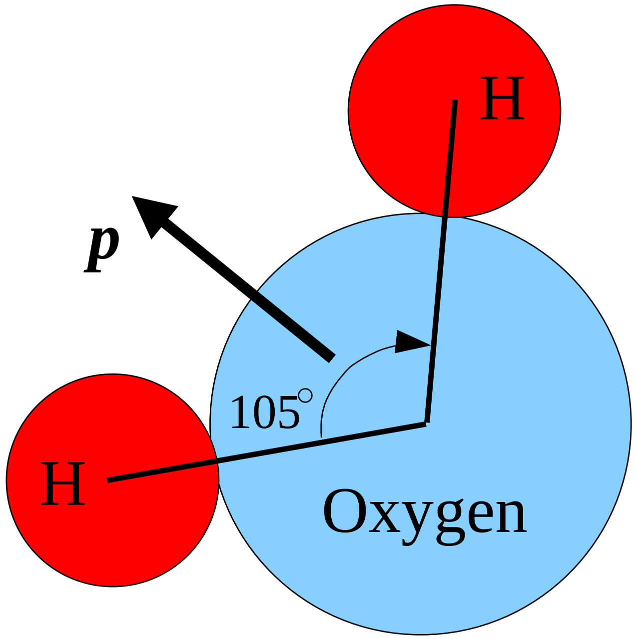
$$p = 6.2 \times 10^{-30} C - m$$

where p is NOT the momentum, but defined as $p = qd$ where d is the separation between between two charges $+q$ and $-q$. Treating this system like a negative charge of 10 electrons and a positive charge of $10e$, the effective separation of the negative and positive charge centers is

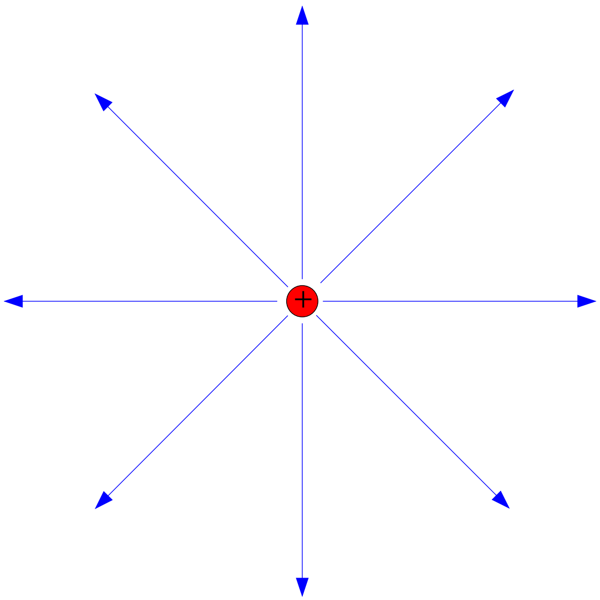
$$d = \frac{p}{10e} = 3.9 \times 10^{-1}$$

This is $0.0039\ nm$ compared with about $0.15\ nm$ for the effective radius of hydrogen in liquid form, so the charge separation is small compared to an atomic radius.



The Electric Potential of a Point Charge

Calculate the electric potential due to a point charge in terms of the radial distance from the charge r, the amount of charge q, and any other necessary constants. A plot of the fields lines is shown to the right.



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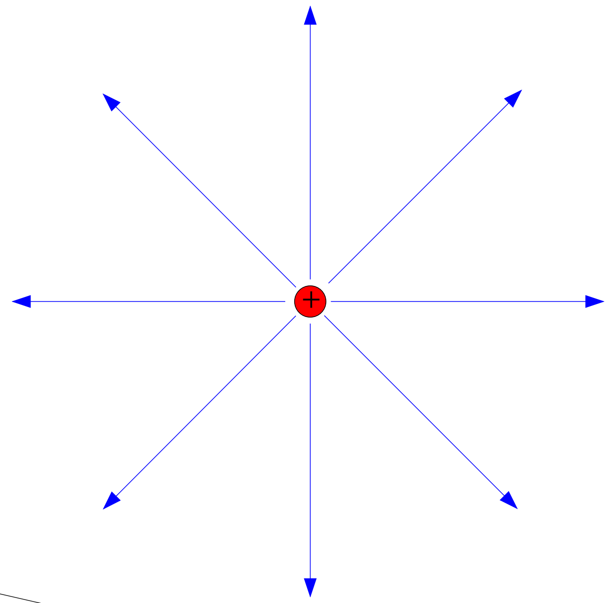
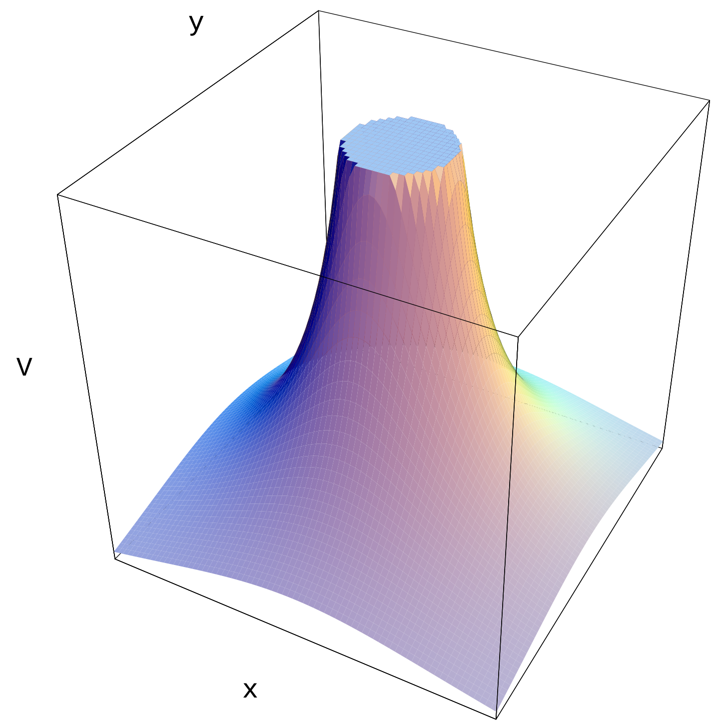
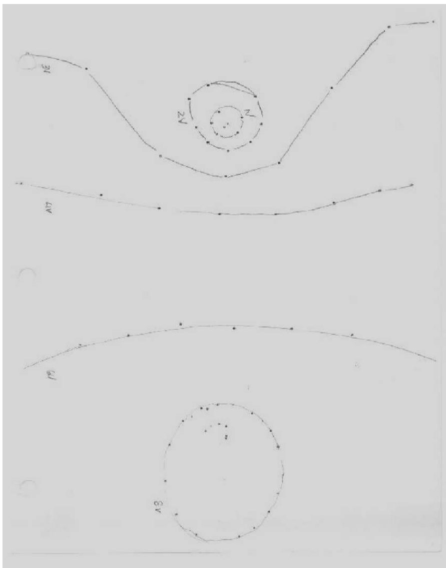
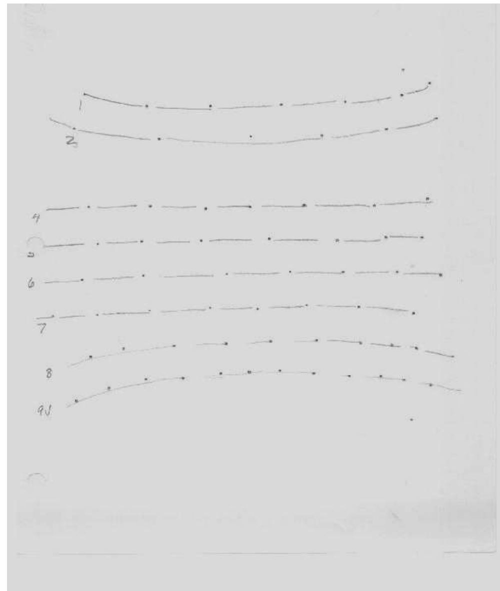




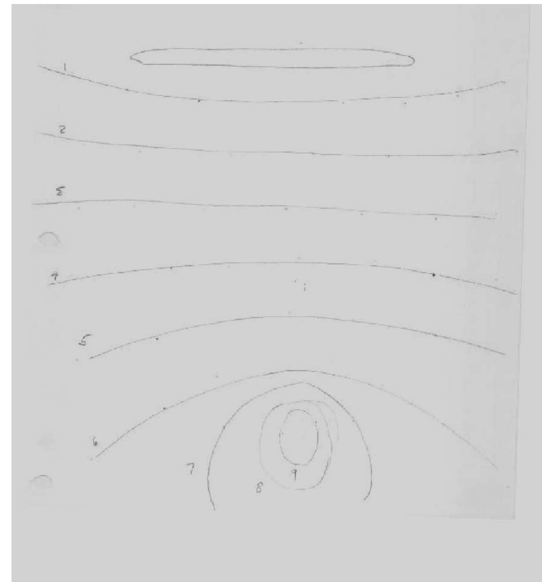
‘Electric Fields and Equipotentials’ lab results



two point charges



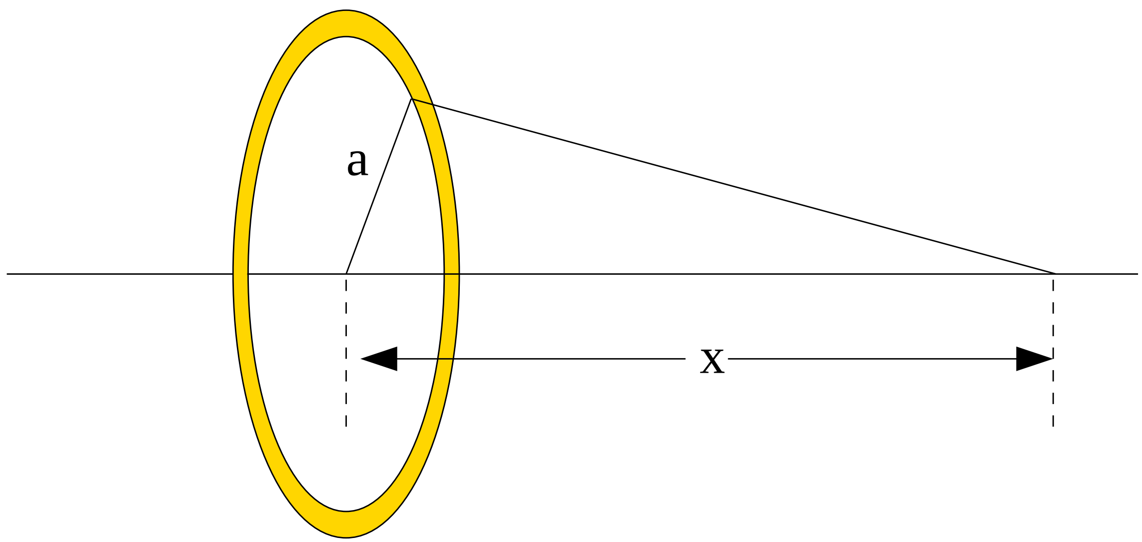
two line charges



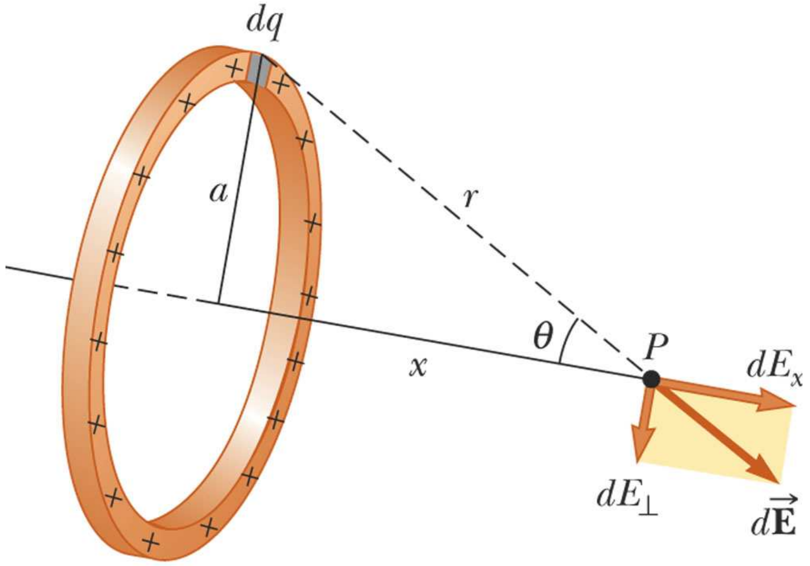
a line and a point charge

The Charged Ring

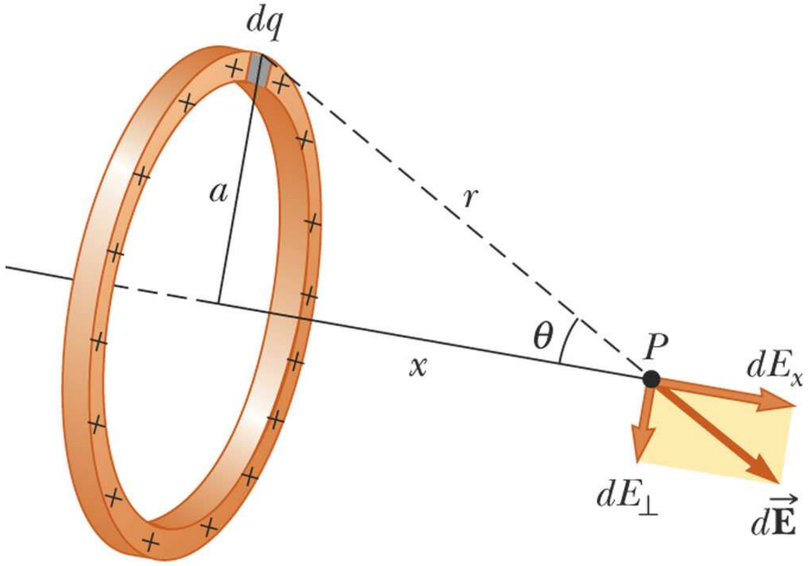
A ring of radius a as shown in the figure has a positive charge distribution per unit length with total charge Q. Calculate the electric field $\vec{E}$ along the axis of the ring at a point lying a distance x from the center of the ring. Get your answer in terms of a, x, Q.

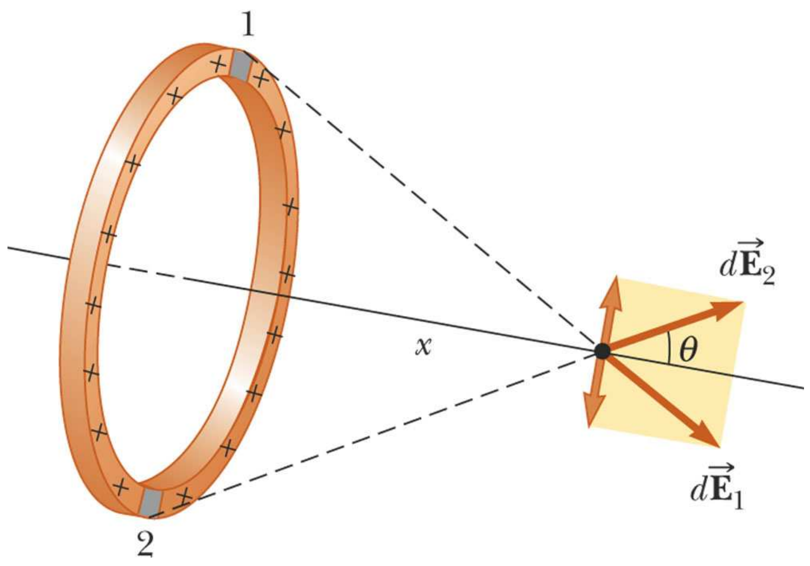


The Charged Ring



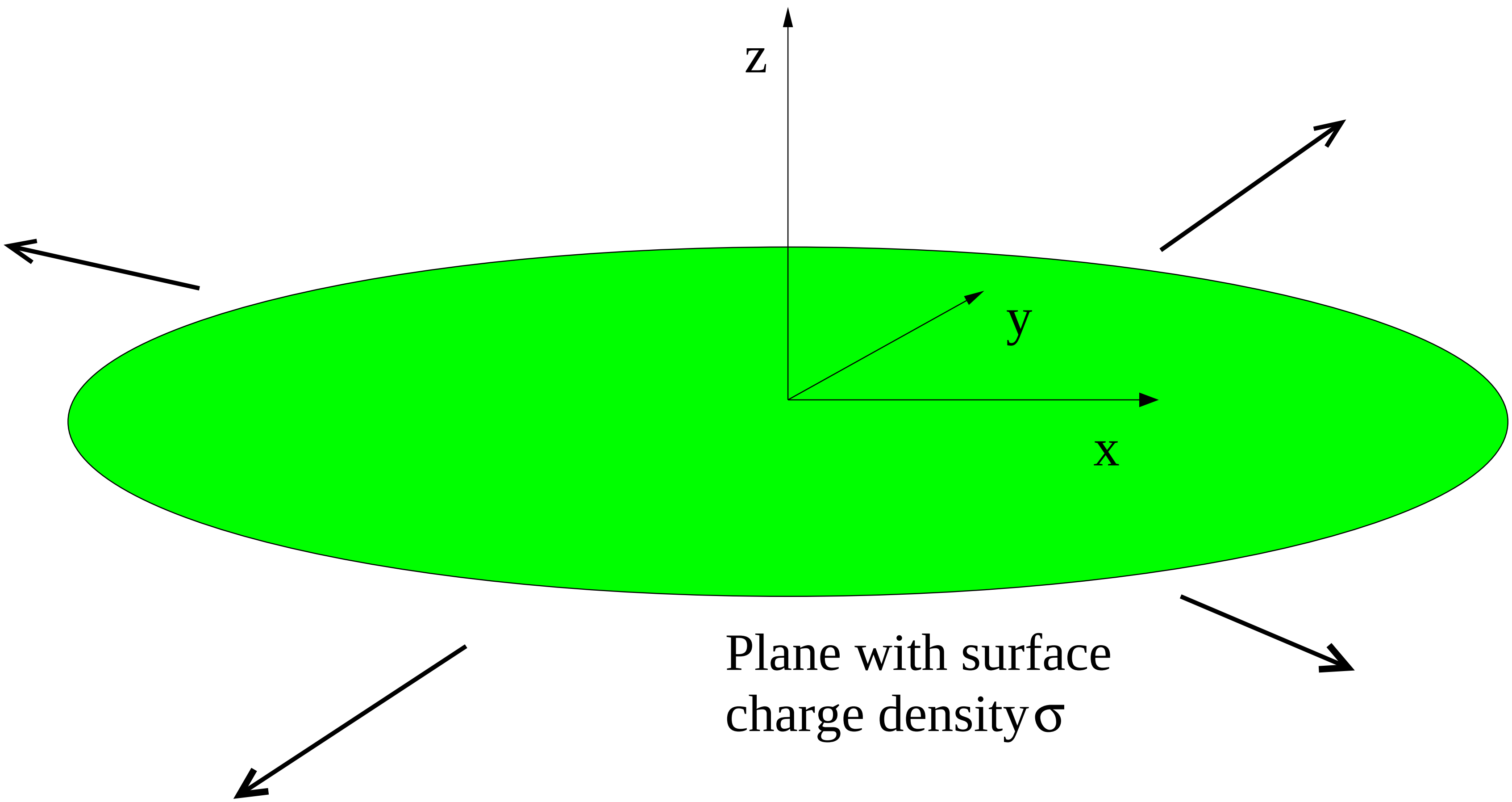
The Charged Ring





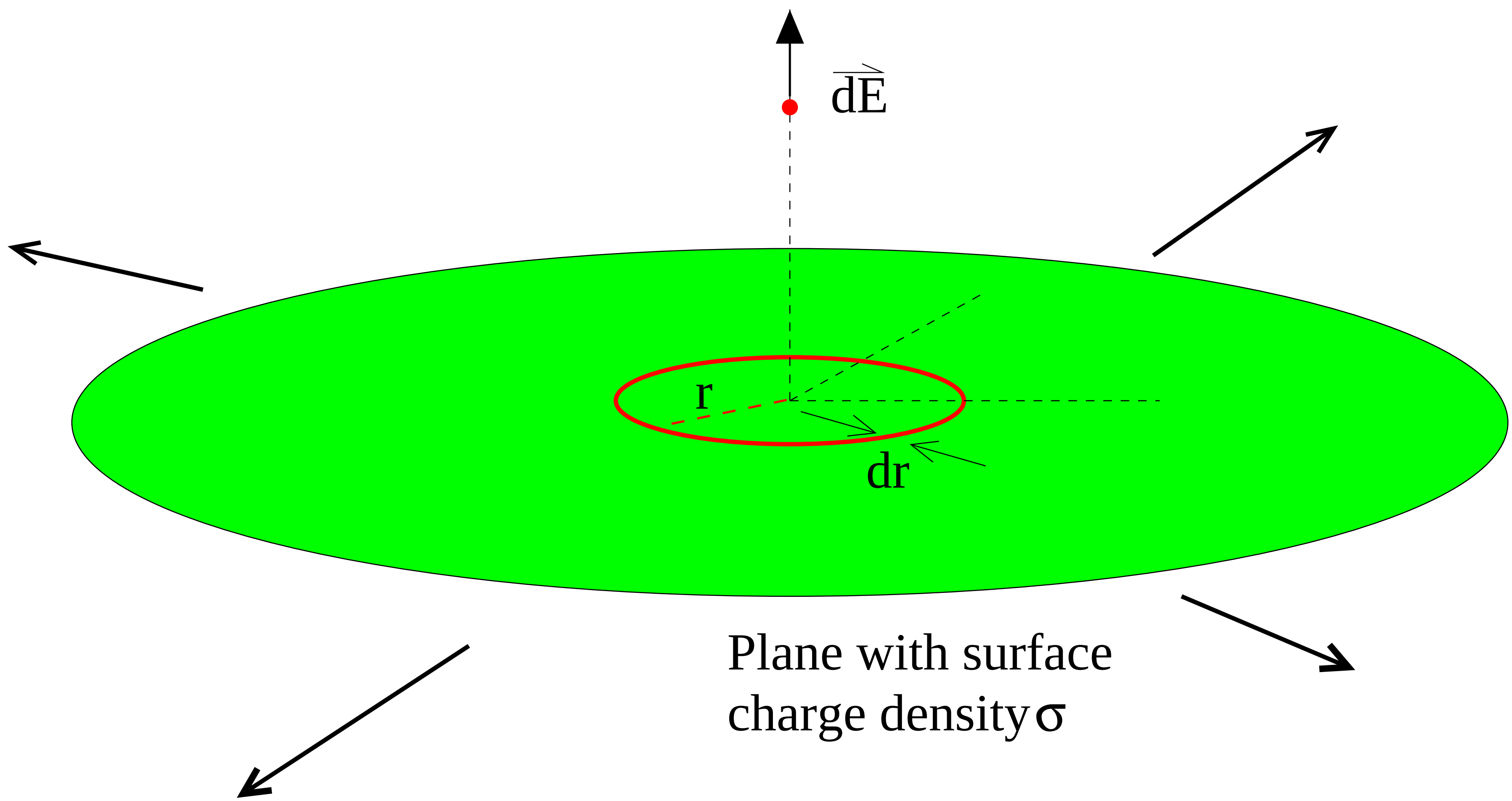
The Charged Disk - 1

Consider an infinitely-large, flat plate covered with a uniform distribution of charge on its surface σ. What is the electric field above the plate in terms of this surface charge density σ and any other constants? What is the electric potential?



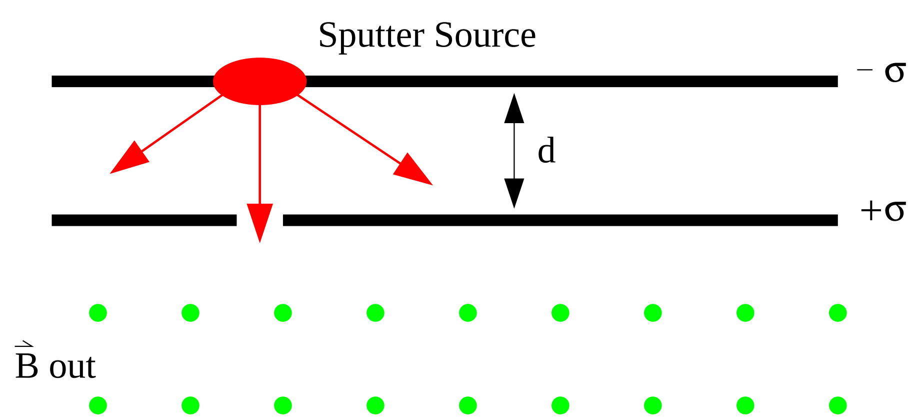
The Charged Disk - 2

Consider an infinitely-large, flat plate covered with a uniform distribution of charge on its surface σ. What is the electric field above the plate in terms of this surface charge density σ and any other constants? What is the electric potential?

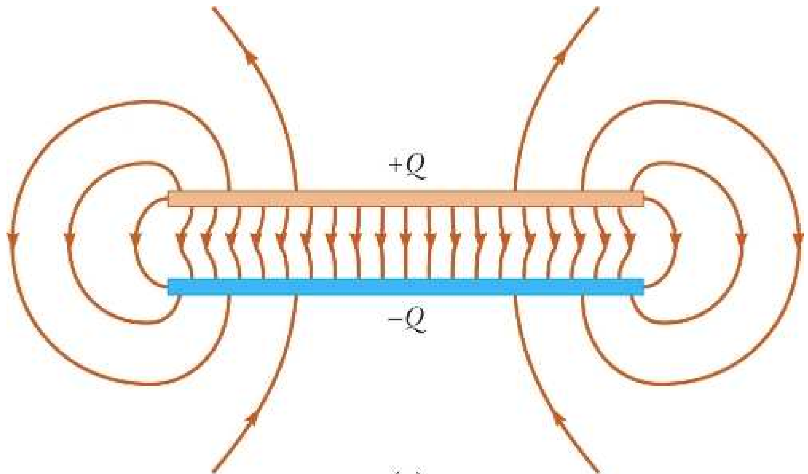


The Acceleration Phase

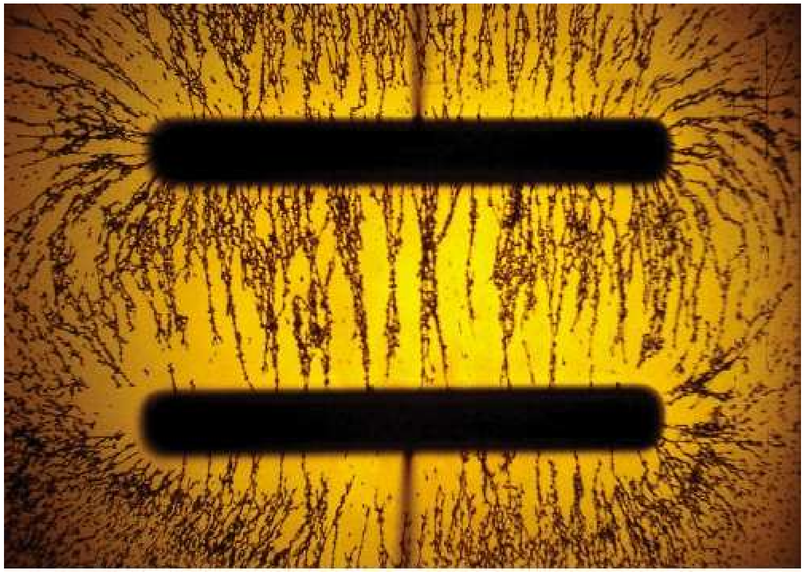
The starting point of a magnetic spectrometer is an accelerator that pushes atoms with a single, added electron to a final velocity before injection into the magnetic part of the spectrometer (see figure). The accelerator consists of two, large, flat, metal plates with surface charge densities $\pm\sigma$ on each plate and separated by a distance d. Charged particles are 'sputtered' from a source and speed up as they cross between the plates. What is the electric potential across the plates in terms of the charge density and the separation d? What is the velocity of a charged particle after it leaves the accelerator? What is the velocity of a ${}^{12}\mathrm{C}^{-}$ ion after it leaves the accelerator if $d = 0.1\ m$ and $\sigma = 8.85 \times 10^{-8}\ C/m^2$?



The Parallel Plate Electric Field



(a)



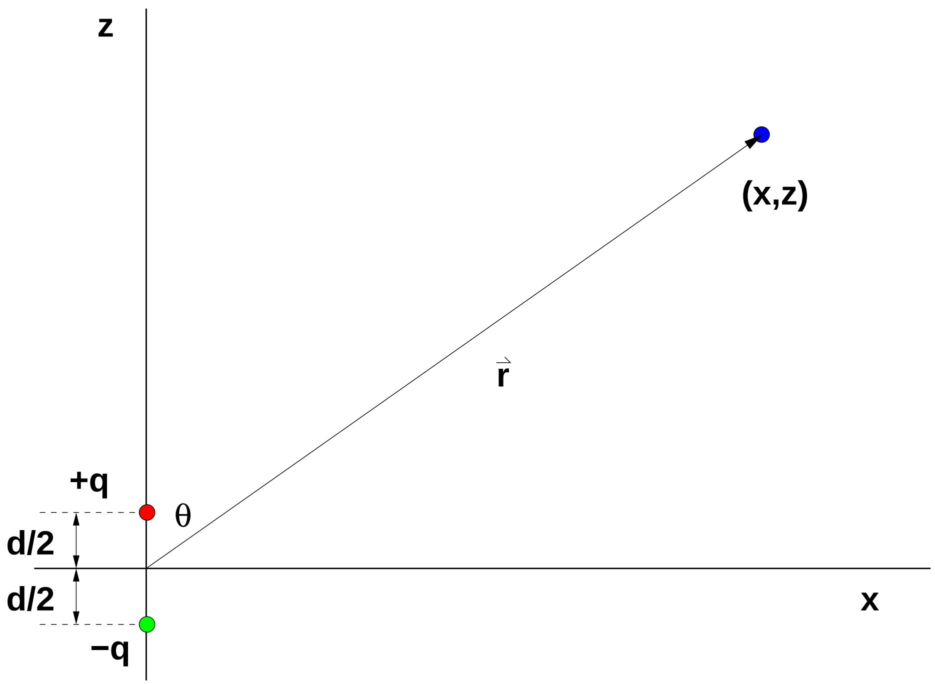
Going from V to $\vec{E}$

The electric potential in the $x - z$ plane of the electric dipole in the figure can be written as

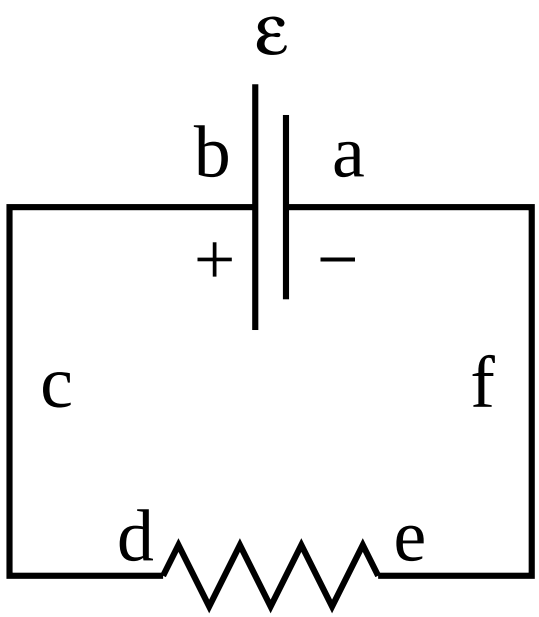
$$V(r, \theta) = k_e p \frac{\cos\theta}{r^2}$$

where r and θ are polar coordinates as defined in the figure, $p = qd$ is the dipole moment, q is the charge, d is the charge separation, and $r >> d$.

What is the electric potential in terms of Cartesian coordinates? What are the x and z components of the electric field?



Electric Circuits - 1



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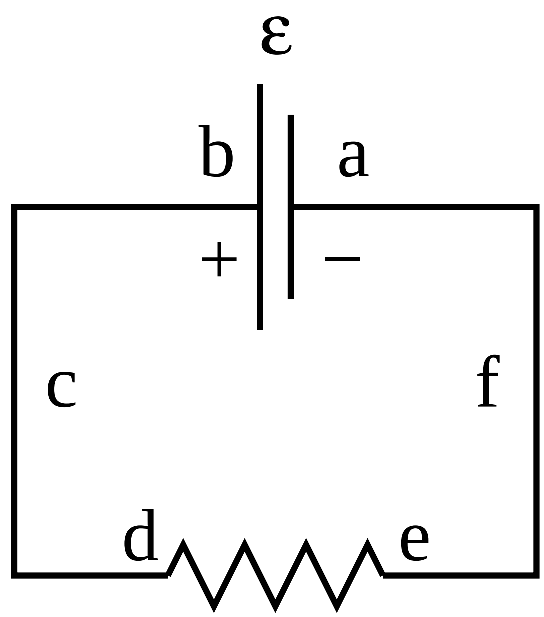
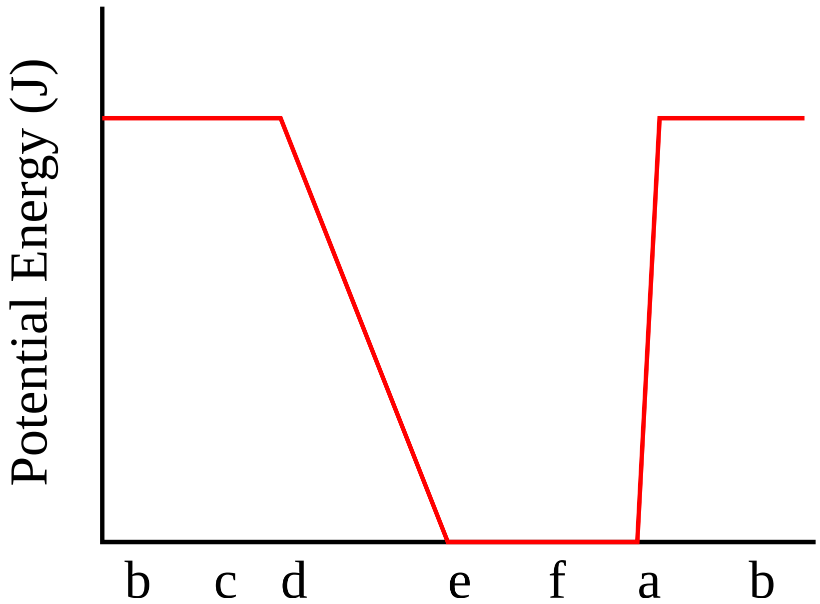
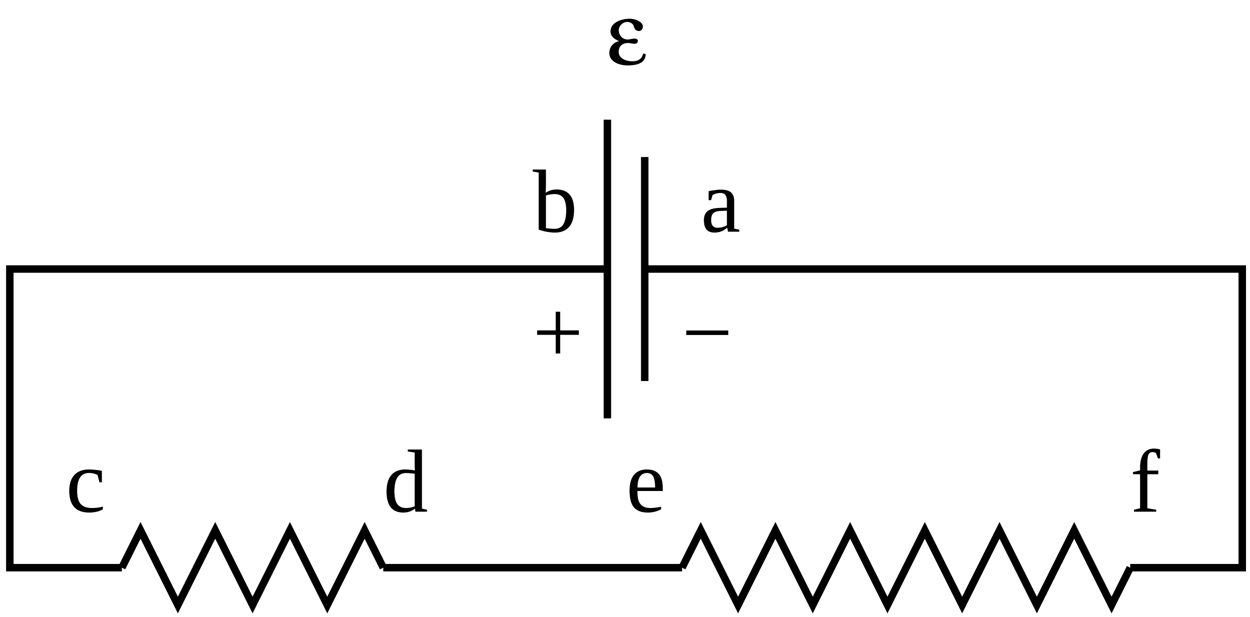
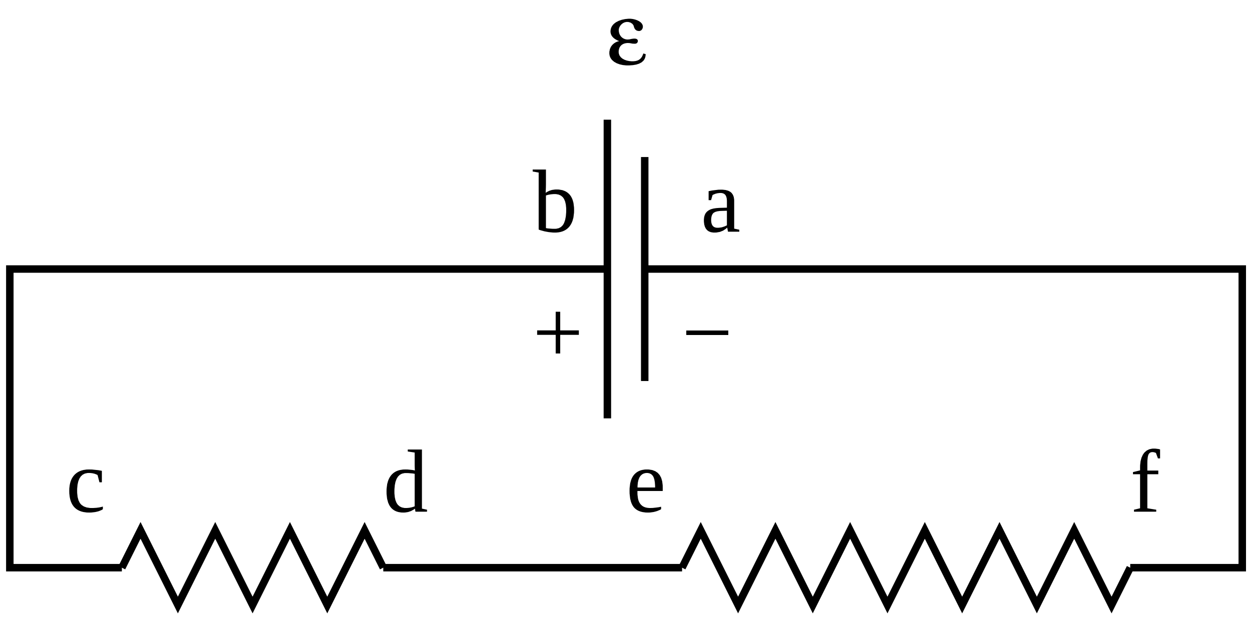


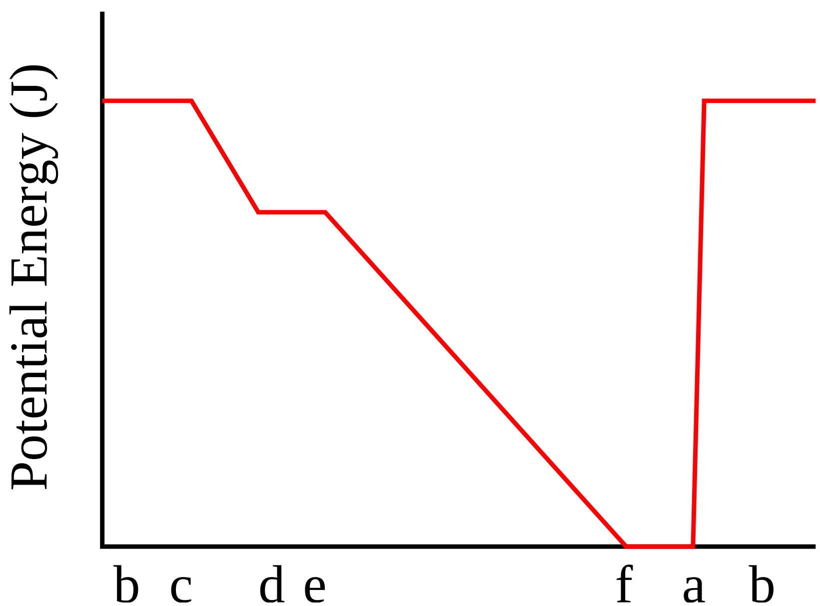


Electric Circuits - 2



Electric Circuits - 2



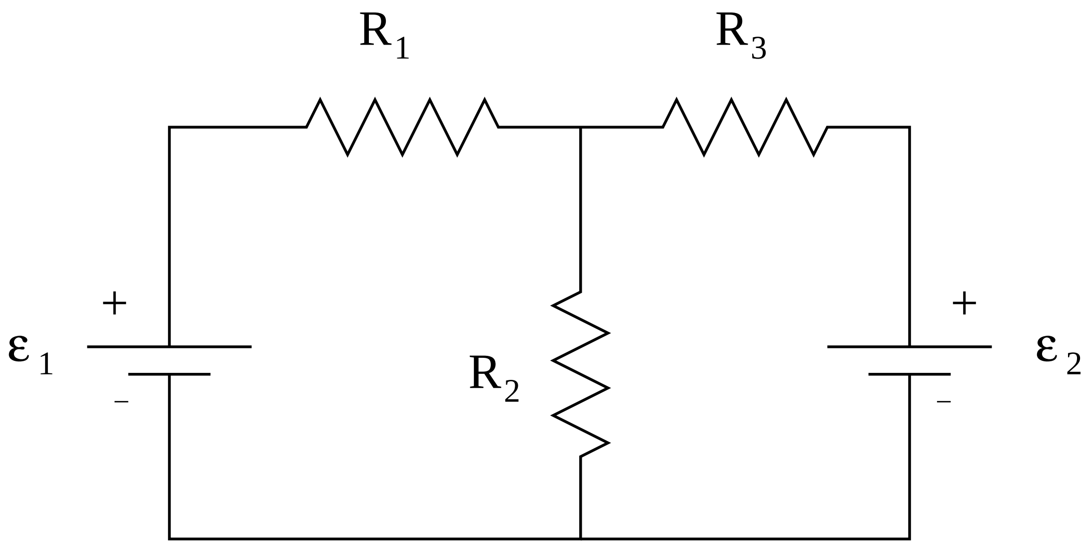


Multiple Loop Circuits

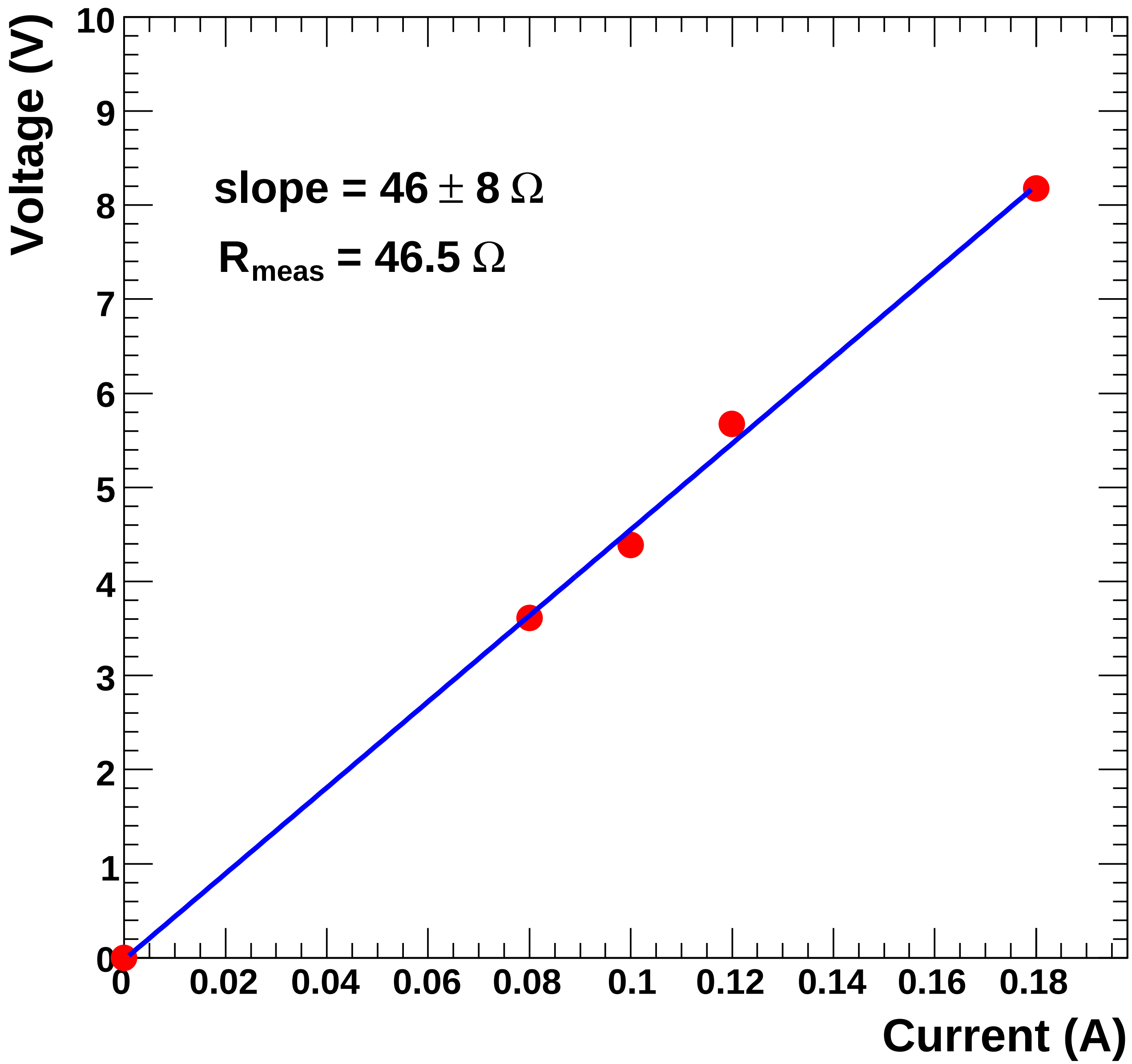
What is the current in each of the resistors in the circuit shown in the figure?

$$R_1 = 4\,\Omega \quad R_2 = 4\,\Omega \quad R_3 = 2\,\Omega$$

$$\epsilon_1 = 16\,V \quad \epsilon_2 = 12\,V$$



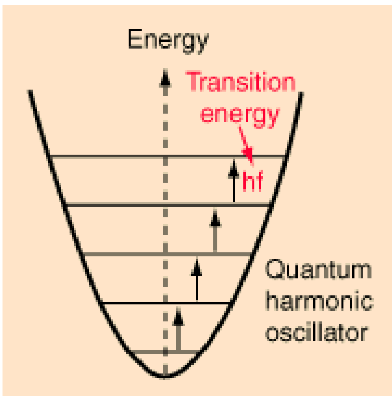
Ohm's Law



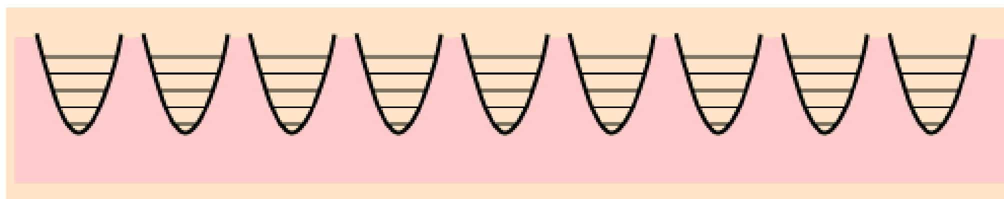
2007-10-16 11:35:02

The Drift Velocity of Conduction Electrons - 1

We are using the *free-electron model* to describe the conduction electrons in a metal. In this model these electrons are free to move about the entire volume of the metal and behave like the molecules or atoms of a gas in a closed container. This is a product of quantum mechanical tunneling.

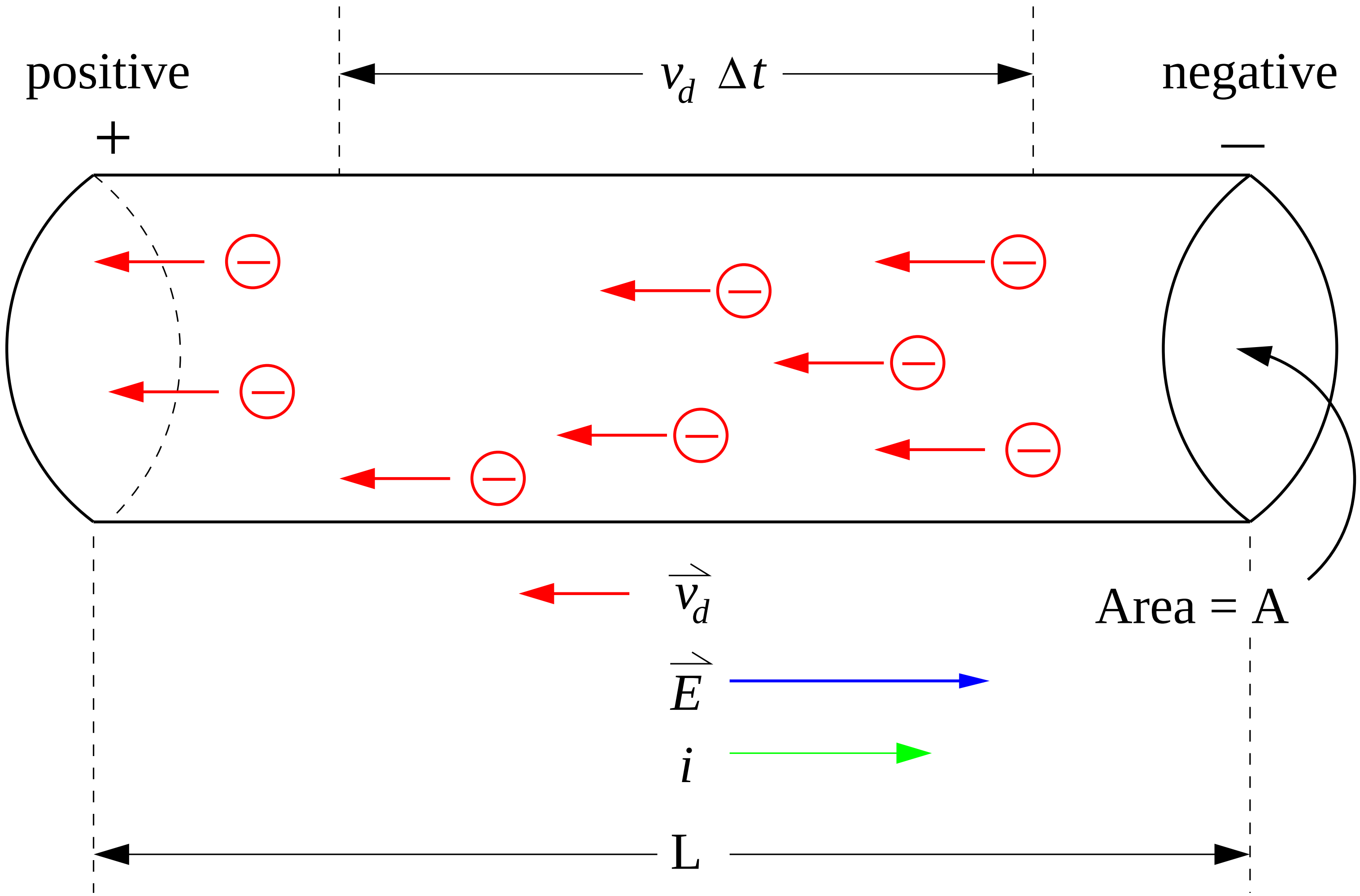


Potential energy of an electron in a single atom.



Potential energy of an electron in a metal.

The Drift Velocity of Conduction Electrons - 2



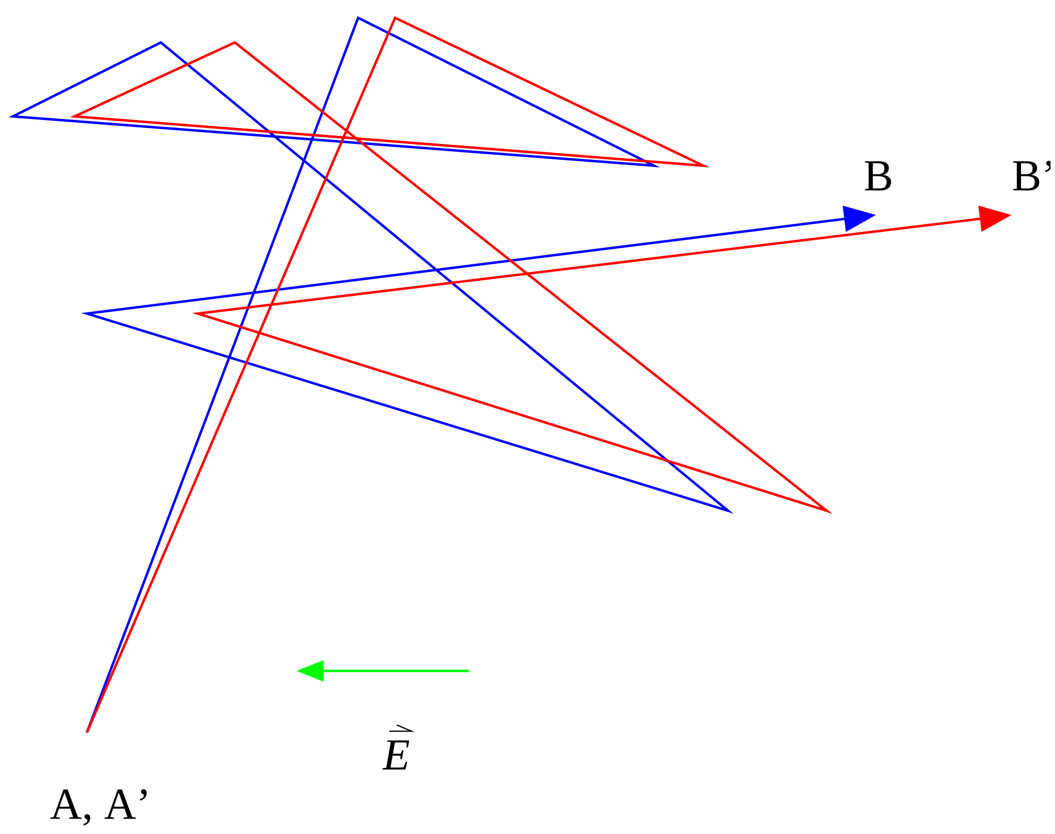
The Drift Velocity of Conduction Electrons - 3

A copper wire carrying $i = 20\ C/s$ has a cross sectional area of $A = 7.1 \times 10^{-6}\ m^2$. The number density of conduction electrons in copper is $n = 8.46 \times 10^{28}\ particles/m^3$. What is the drift velocity $\vec{v}_d$ of the conduction electrons? What is the average speed of electrons in the metal at a temperature $T = 25°C$? How do these two velocities compare with each other? Recall the relationship between temperature and the average kinetic energy of particles in a gas.

$$\langle KE \rangle = \frac{1}{2} m_2 v_{rms}^2 = \frac{3}{2} k_B T$$

The Drift Velocity of Conduction Electrons - 4

Electron Paths in a Metal

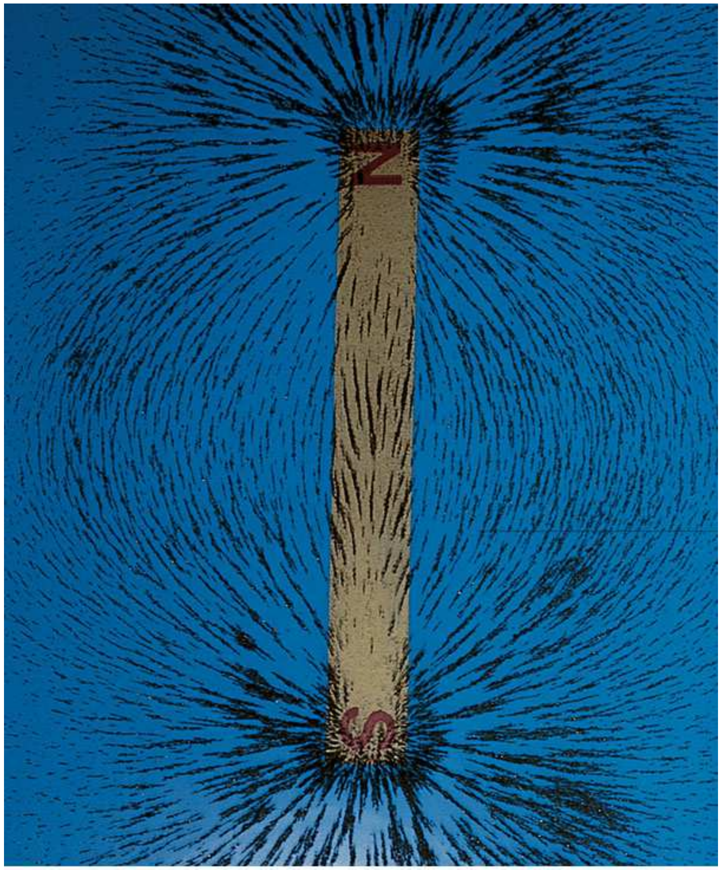


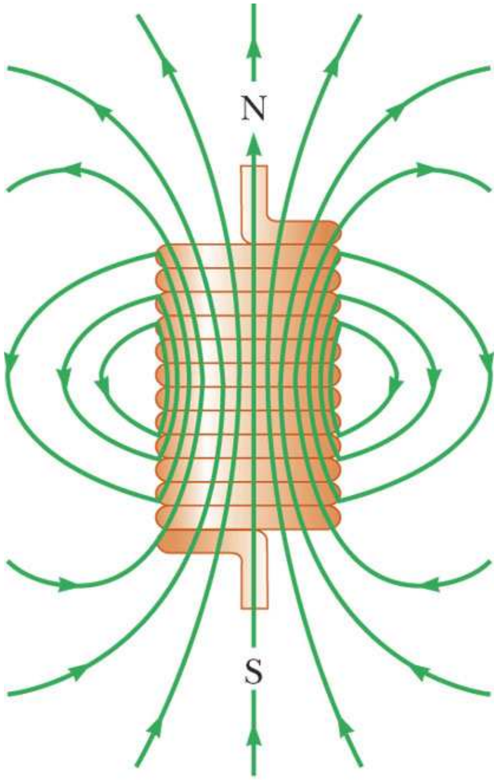
Blue: No applied voltage or field
Red: Voltage applied.

Resistivities of Materials at Room Temperature

Material	Resistivity	Type of Material
Silver	1.62×10^{-8}	Metal
Copper	1.69×10^{-8}	Metal
Aluminum	2.75×10^{-8}	Metal
Iron	9.68×10^{-8}	Metal
Silicon, pure	2.5×10^{-3}	Semiconductor
Silicon, n-type	8.7×10^{-3}	Semiconductor
Glass	$10^{10} - 10^{14}$	Insulator
Quartz	$\approx 10^{16}$	Insulator

The Magnetic Dipole Field

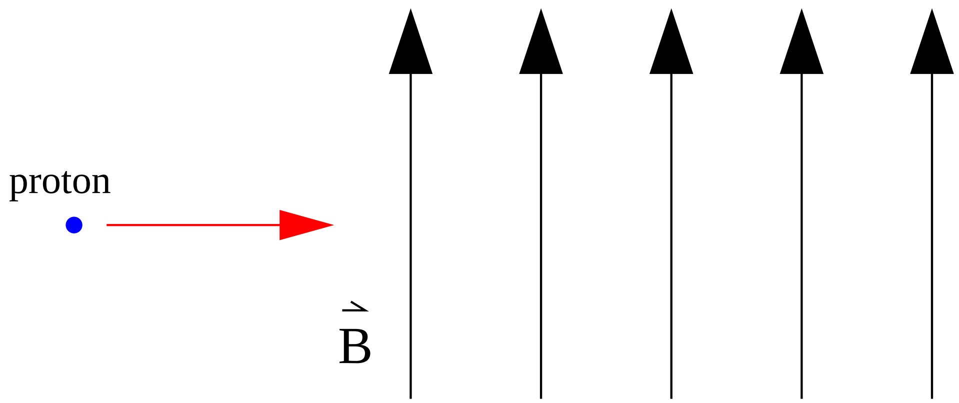




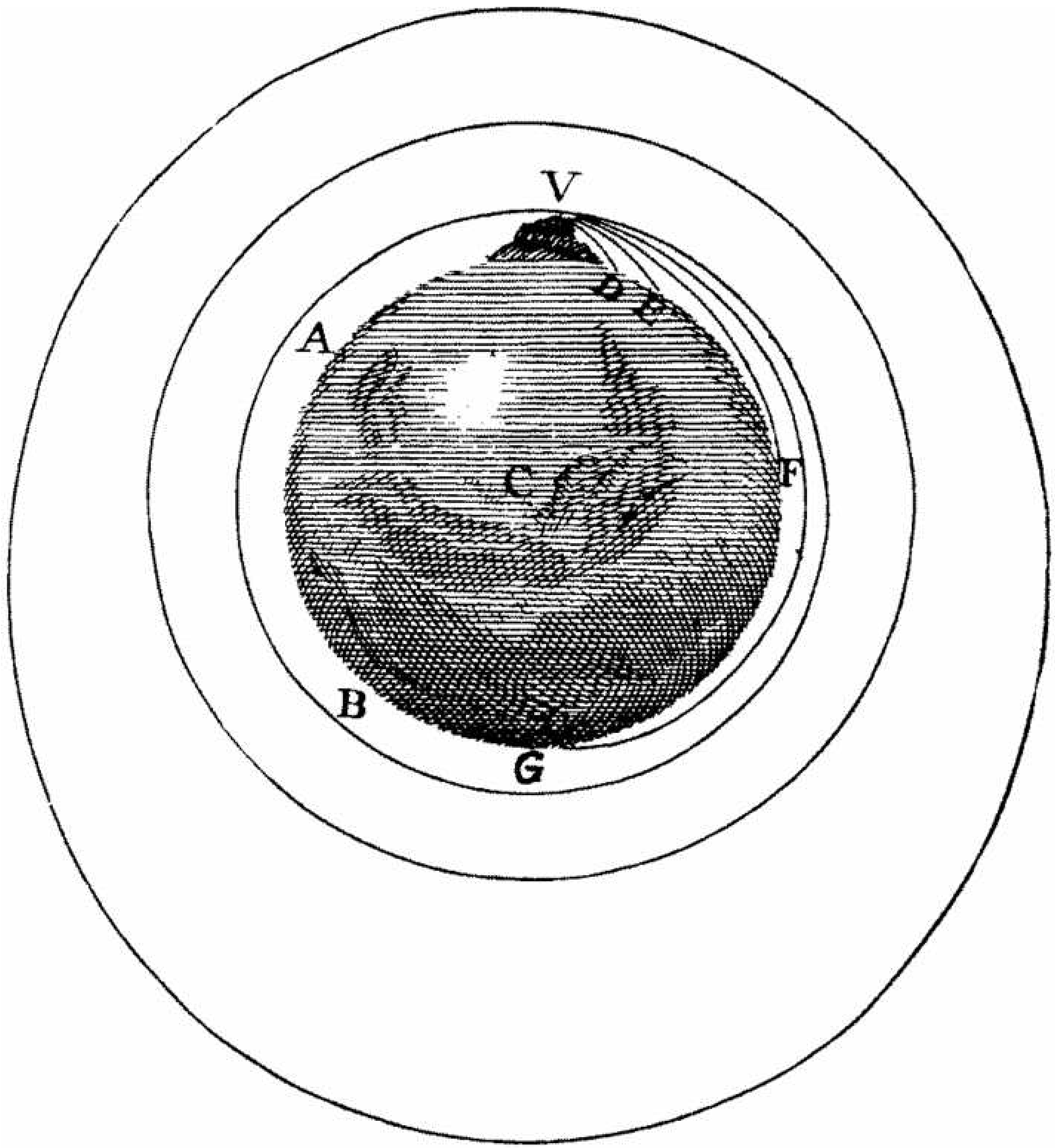
(a)

The Magnetic Force

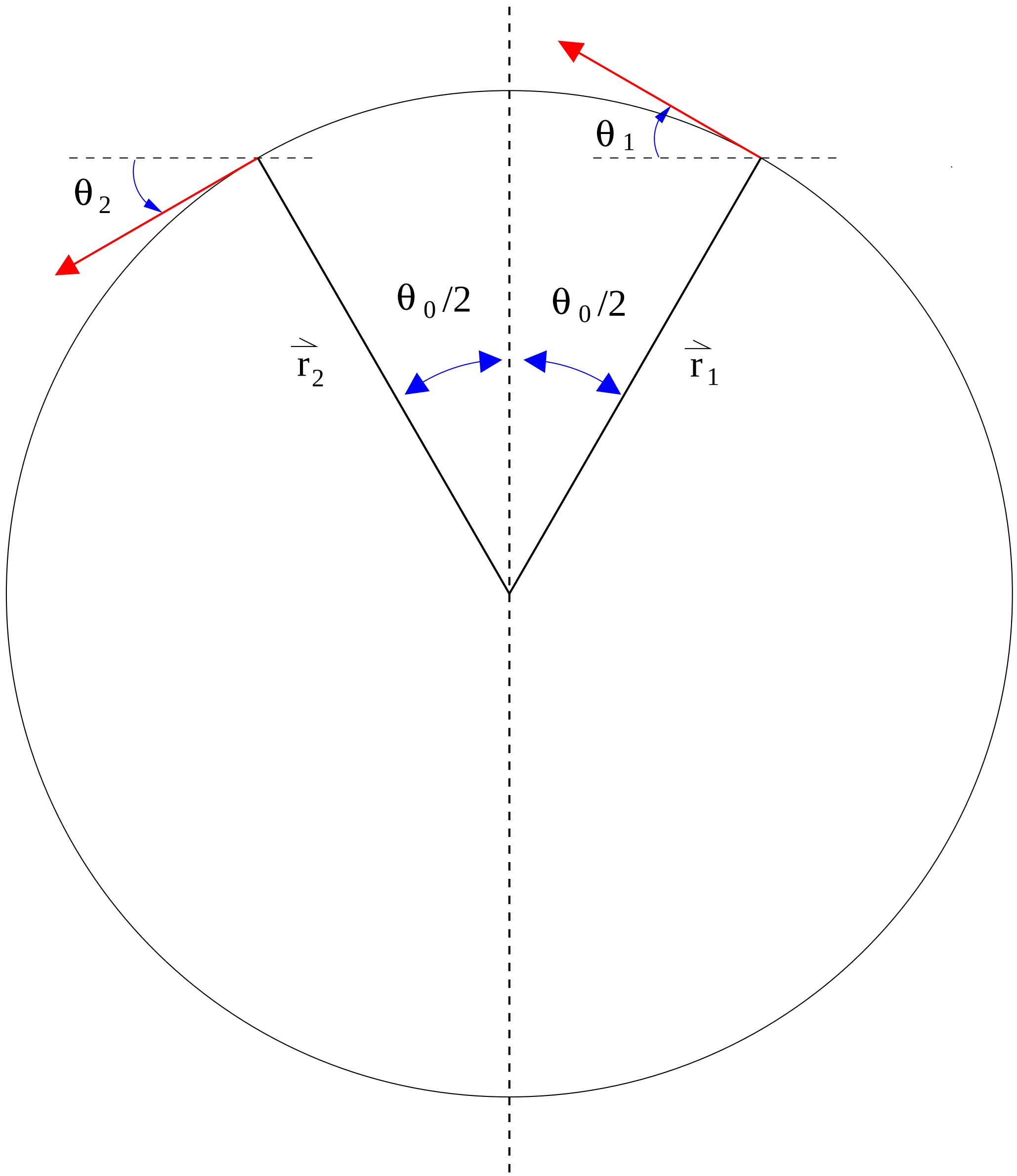
A uniform magnetic field has a magnitude $|\vec{B}| = 1.2\,T$ and points straight up. A proton with energy $E = 5.3\,MeV$ enters the field moving horizontally. What is the magnitude and direction of the force on the proton? How would the force change for an electron moving with the same initial velocity? Describe the trajectory of the particle.



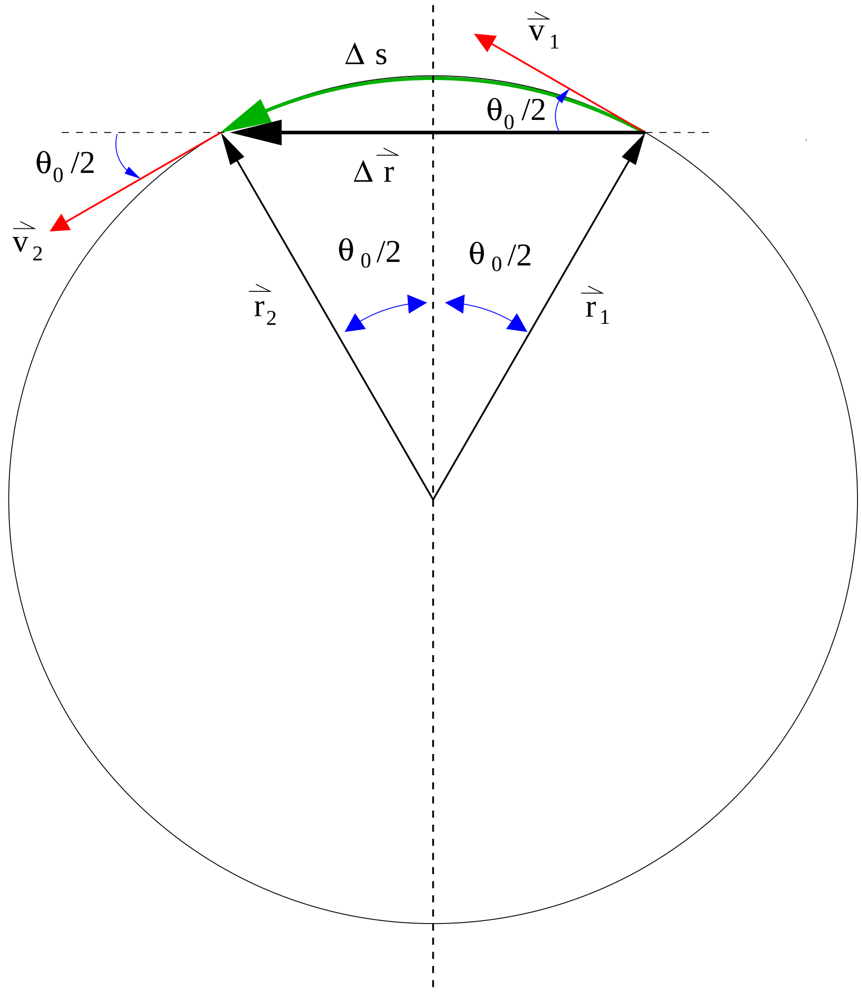
Centripetal Force - 1



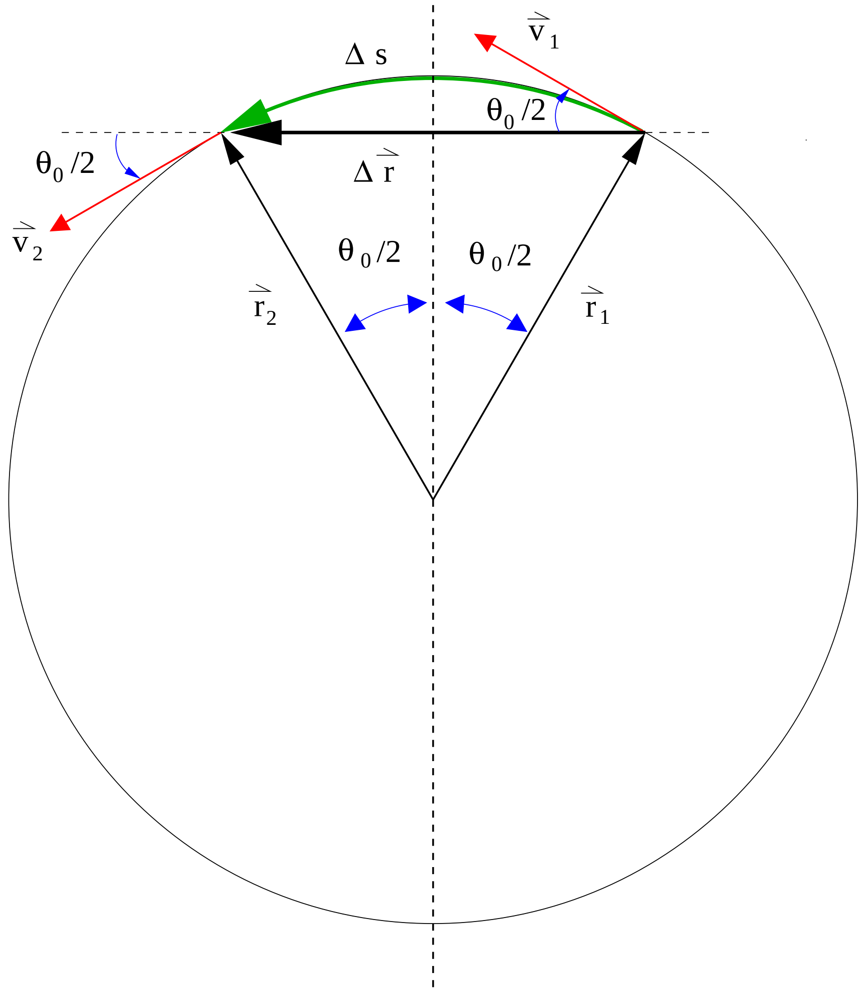
Centripetal Force - 2

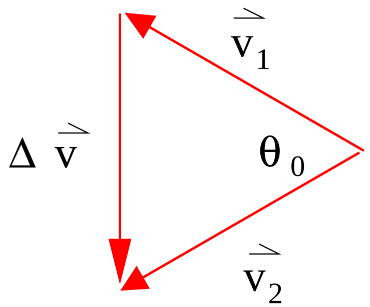


Centripetal Force - 3

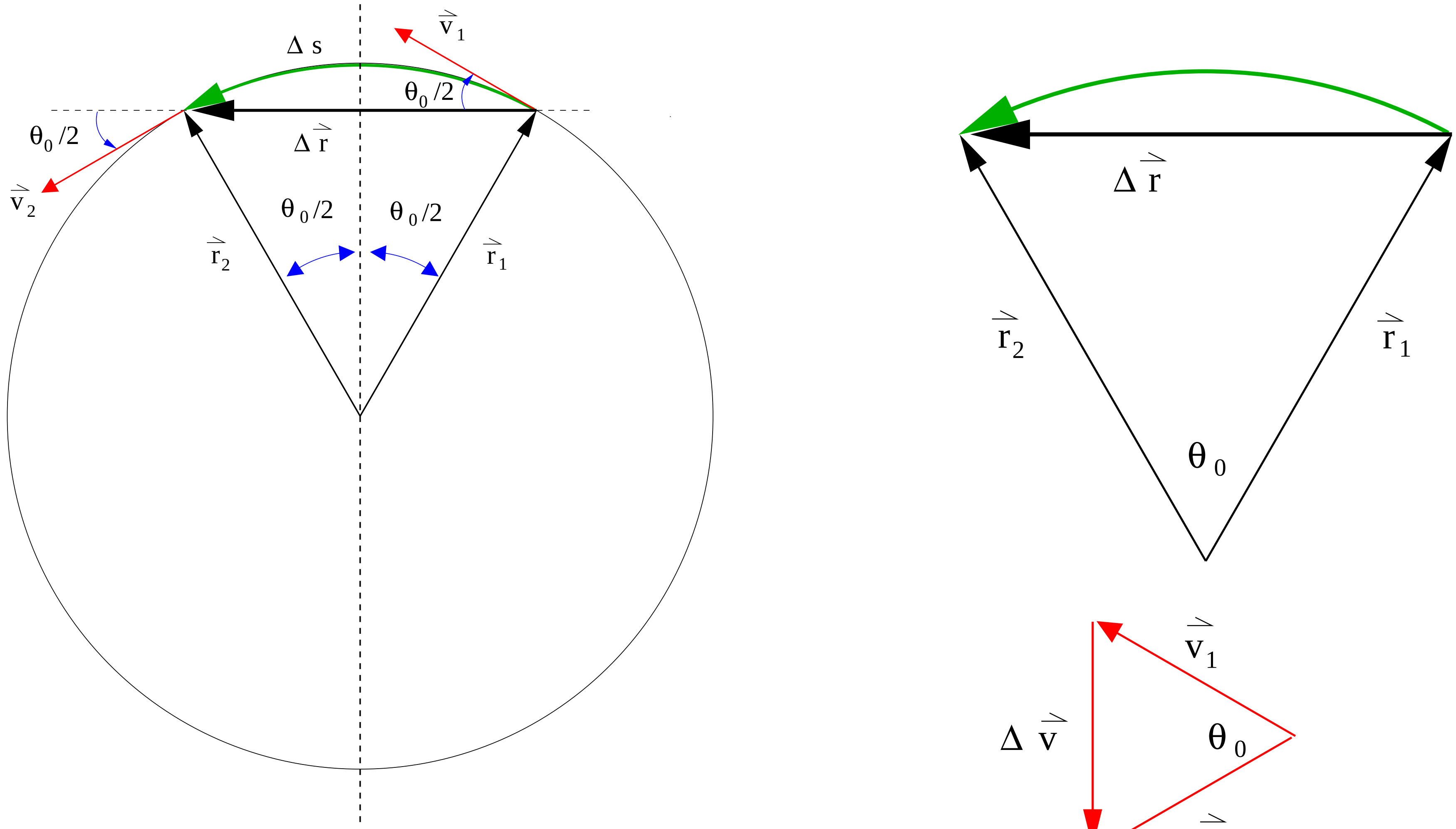


Centripetal Force - 3





Centripetal Force - 3



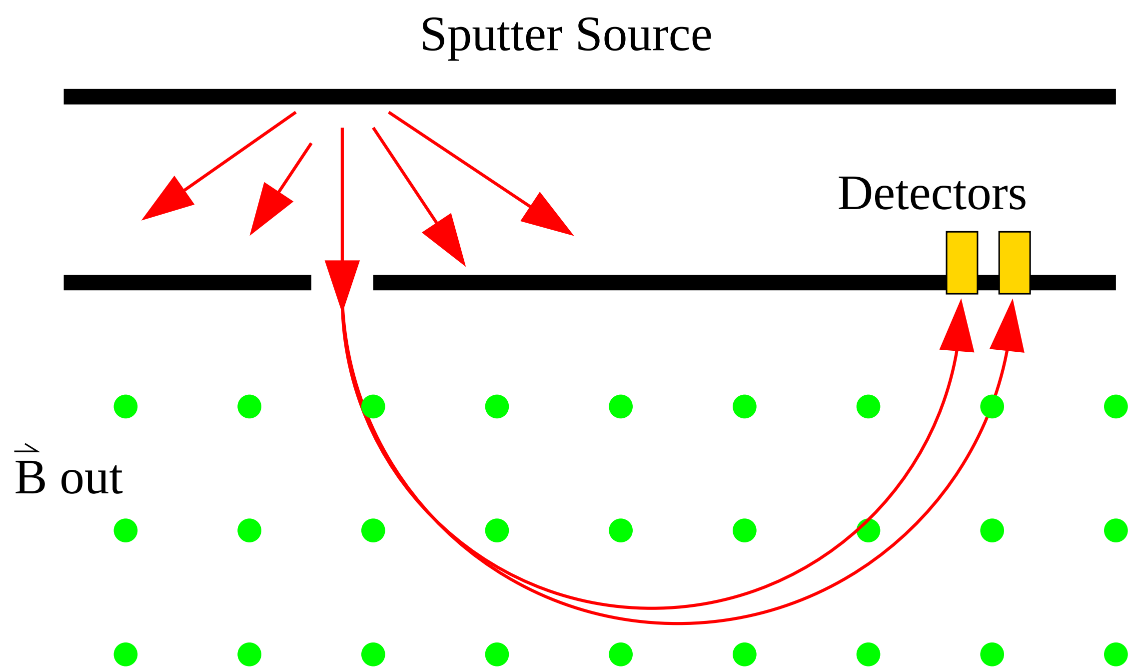
Centripetal Force on the Earth

As we stand on the Earth's surface we orbit the center of the planet. A centripetal acceleration a_c is required to maintain our circular orbit, otherwise we might go flying off into outer space. How does this acceleration a_c compare with the known acceleration of gravity g at the Earth's surface? At what speed will things start to 'fly off' the Earth's surface? At this 'fly-off' speed, what is the length of one day?

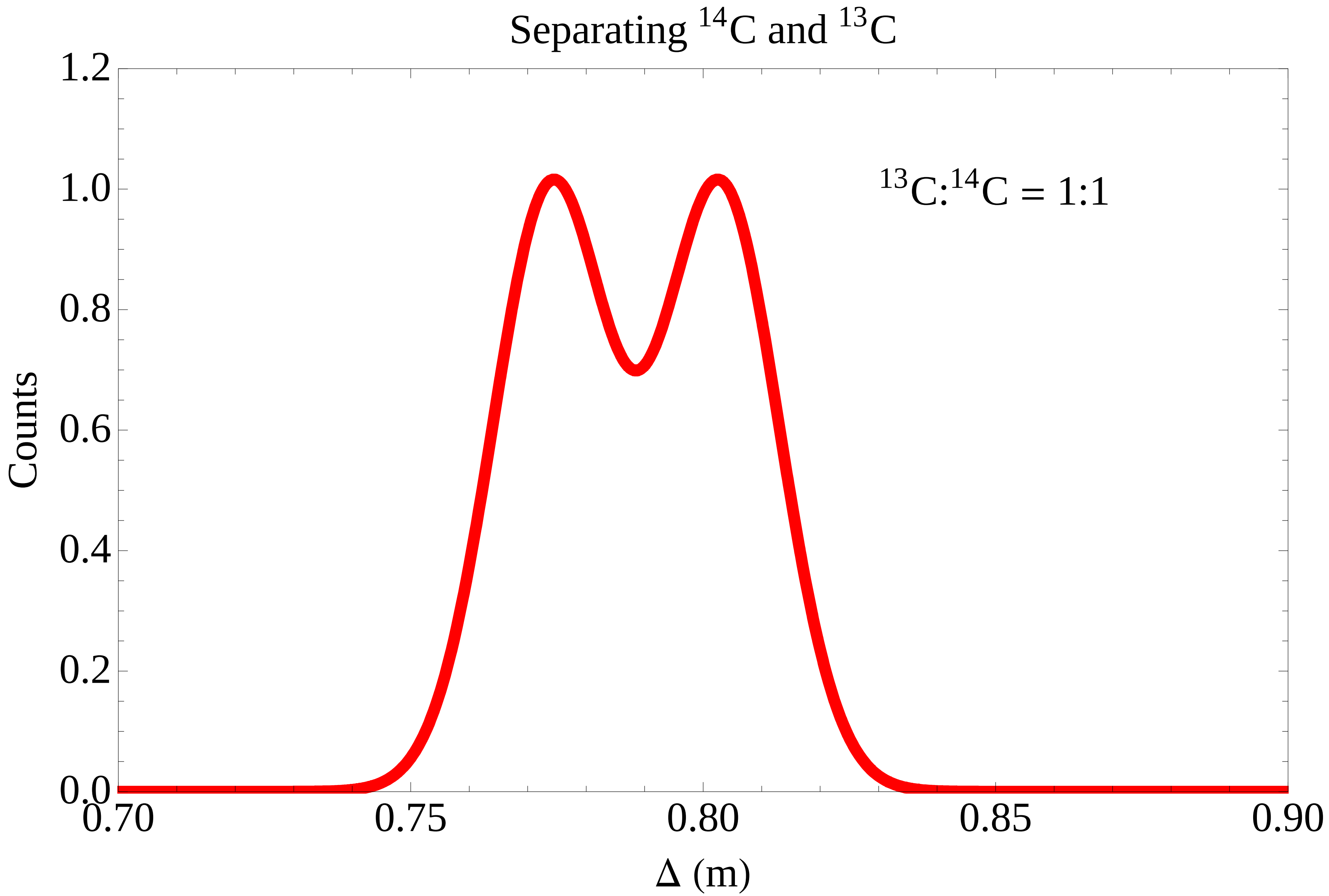
Earth's radius: $6.37 \times 10^6\, m$ g $9.8\, m/s^2$

Radiocarbon Mass Spectrometry

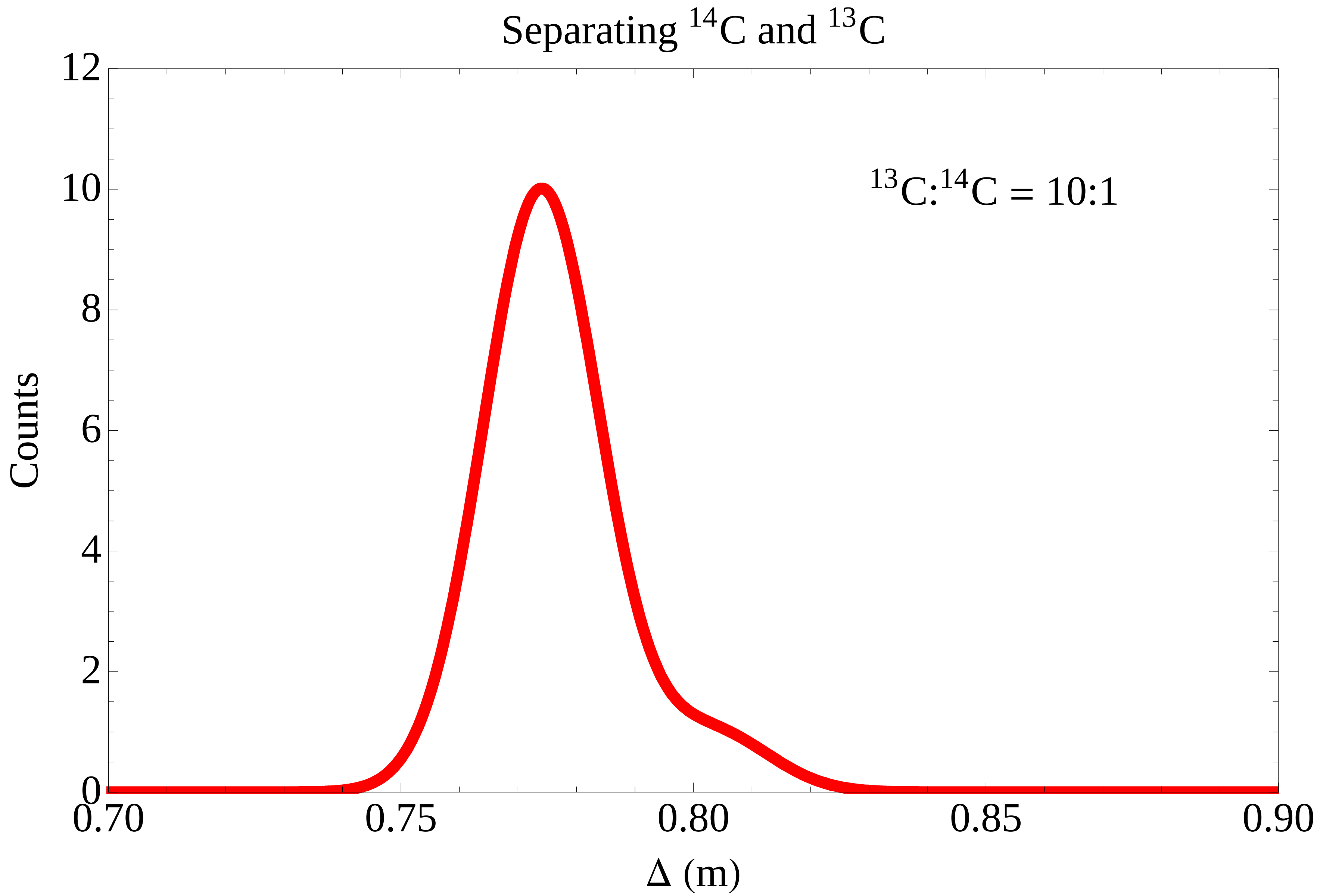
Two isotopes of carbon, $^{13}\mathrm{C}$ and $^{14}\mathrm{C}$ are accelerated across a potential difference $V = 5.0 \times 10^6\ V$. Each atom carries an extra electron so $q = -e = -1.6 \times 10^{-19}\ C$. The atoms are moving horizontally when they enter a uniform magnetic field pointing straight up with $B = 3.0\ T$. The negatively-charged atoms follow a semi-circular path before striking detectors that measure their passage. The variation in the trajectory of each atom is such that the variation in their final position is about $\pm 0.01\ m$. Will the spectrometer be able to separate the two isotopes?



Radiocarbon Mass Spectrometry

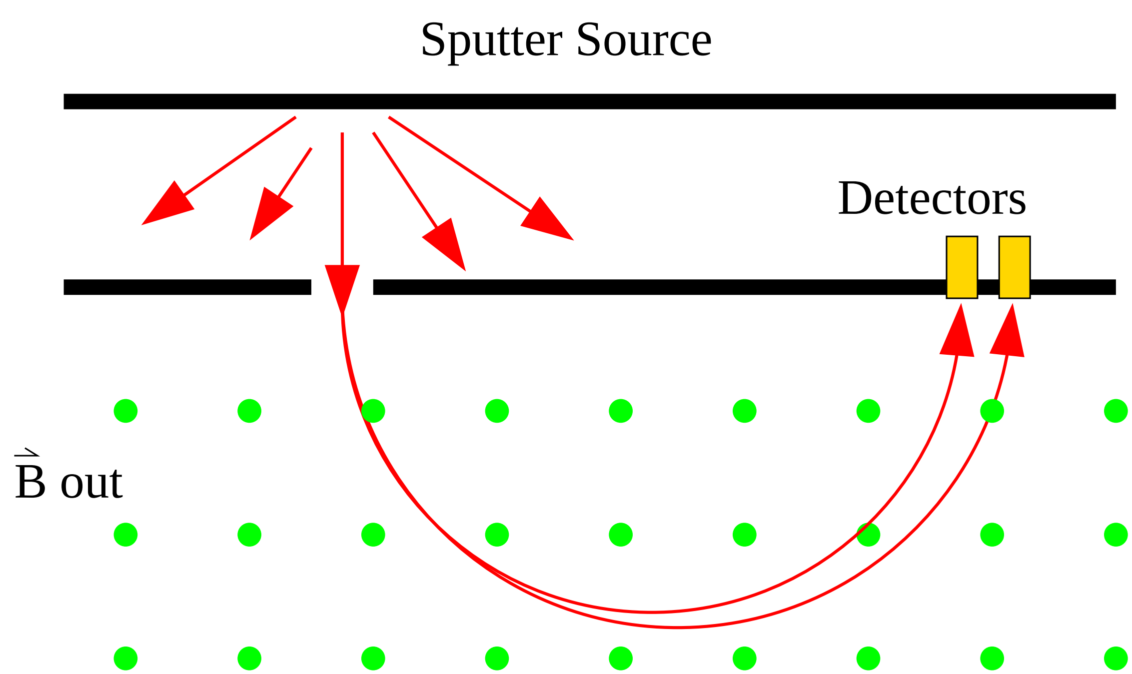


Radiocarbon Mass Spectrometry



Radiocarbon Mass Spectrometry

Two isotopes of carbon, $^{12}\mathrm{C}$ and $^{14}\mathrm{C}$ are accelerated across a potential difference $V = 5.0 \times 10^6\ V$. Each atom carries an extra electron so $q = -e = -1.6 \times 10^{-19}\ C$. The atoms are moving horizontally when they enter a uniform magnetic field pointing straight up with $B = 3.0\ T$. The negatively-charged atoms follow a semi-circular path before striking detectors that measure their passage. The variation in the trajectory of each atom is such that the variation in their final position is about $\pm 0.01\ m$. Will the spectrometer be able to separate the two isotopes?



The Age of the Earth

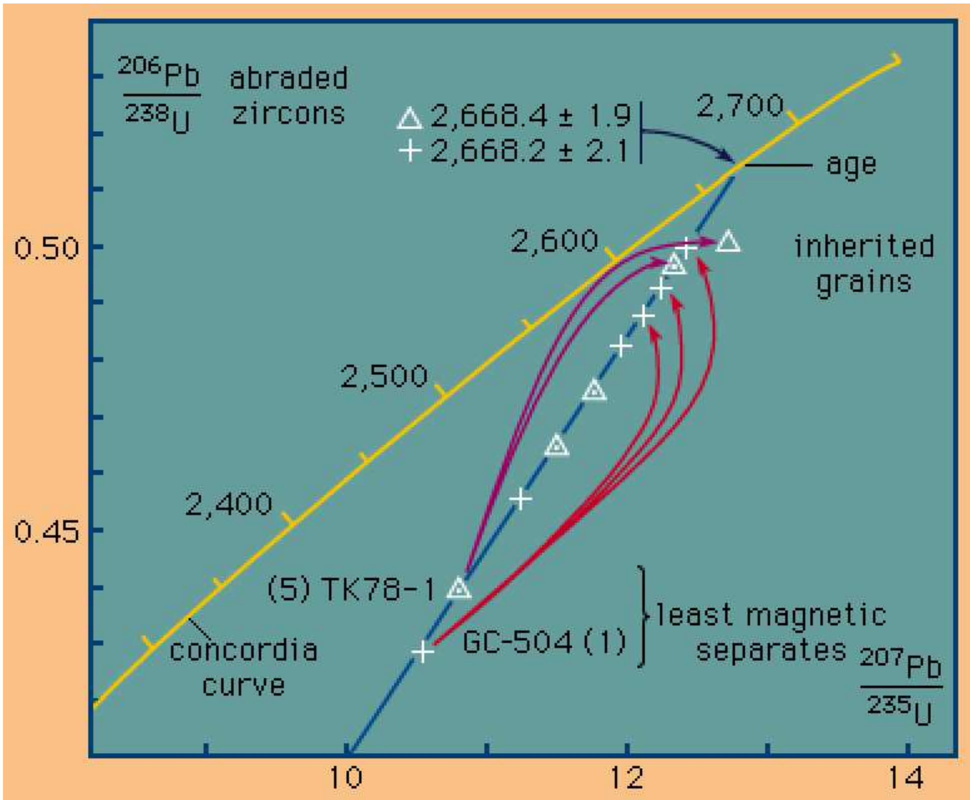
The figure below shows the decay scheme for $^{238}\mathrm{U}$ which can be approximated as $^{238}\mathrm{U} \longrightarrow {}^{206}\mathrm{Pb} +$ other decay products where the half-life is determined by that first step. Why? A rock is found containing $m_U = 0.0042\,kg$ of $^{238}\mathrm{U}$ and $m_{Pb} = 0.0024\,kg$ of $^{206}\mathrm{Pb}$. Assume the rock contained no lead at all when it was formed so all the lead present is from the decay of uranium. What is the age of the rock? What does this say about the age of the Earth?

$$ {}^{238}_{92}\mathrm{U} \xrightarrow[4.5\mathrm{x}10^{9}\,\mathrm{y}]{\alpha} {}^{234}_{90}\mathrm{Th} \xrightarrow[24\,\mathrm{d}]{\beta} {}^{234}_{91}\mathrm{Pa} \xrightarrow[6.7\,\mathrm{h}]{\beta} {}^{234}_{92}\mathrm{U} \xrightarrow[2.5\mathrm{x}10^{5}\,\mathrm{y}]{\alpha} {}^{230}_{90}\mathrm{Th} \xrightarrow[7.4\mathrm{x}10^{4}\,\mathrm{y}]{\alpha} $$

$$ {}^{226}_{88}\mathrm{Ra} \xrightarrow[1600\,\mathrm{y}]{\alpha} {}^{222}_{86}\mathrm{Rn} \xrightarrow[3.8\,\mathrm{d}]{\alpha} {}^{218}_{84}\mathrm{Po} \xrightarrow[3.1\,\mathrm{m}]{\alpha} {}^{214}_{82}\mathrm{Pb} \xrightarrow[27\,\mathrm{m}]{\beta} {}^{214}_{83}\mathrm{Bi} \xrightarrow[20\,\mathrm{m}]{\beta} $$

$$ {}^{214}_{84}\mathrm{Po} \xrightarrow[0.16\,\mathrm{ms}]{\alpha} {}^{210}_{82}\mathrm{Pb} \xrightarrow[22\,\mathrm{y}]{\beta} {}^{210}_{83}\mathrm{Bi} \xrightarrow[5.0\,\mathrm{d}]{\beta} {}^{210}_{84}\mathrm{Po} \xrightarrow[138\,\mathrm{d}]{\alpha} {}^{206}_{82}\mathrm{Pb} $$

Testing the No-Lead Assumption



Uranium-lead discordia line for isotopic results for zircons from two 2,668-million-year-old granites. Data for different fractions of zircon define a straight line with points plotting between 3 and 18 percent below the curve. The data for the least magnetic fractions represent the starting material in a series of tests designed to obtain data closer to the curve. The grains analyzed to obtain these data at the top of the arrows were selected to be crack-free, and all had natural surfaces removed by abrasion. These give the most reliable age information as extrapolations are reduced (see text).

Testing the No-Lead Assumption

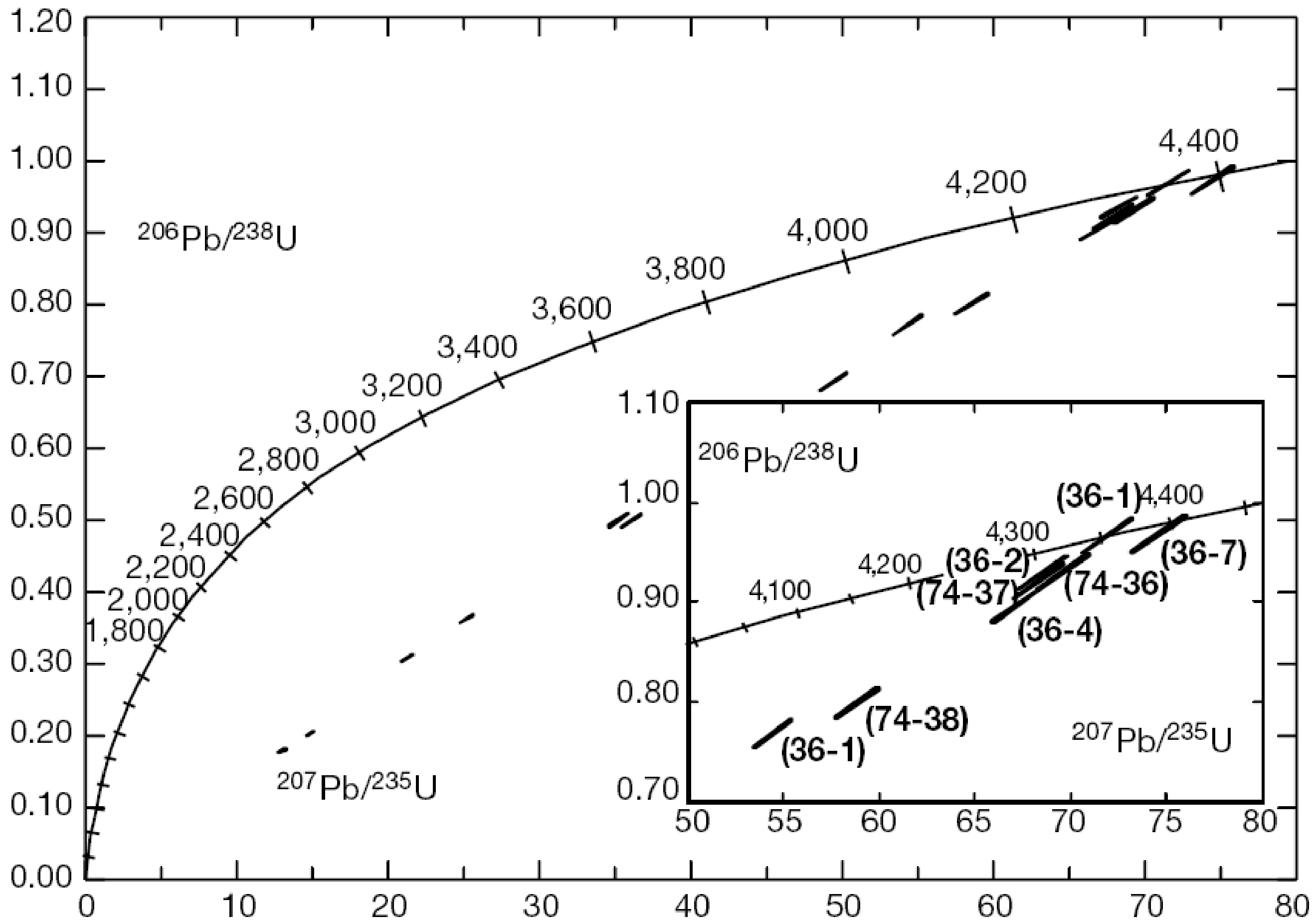


Figure 2 Combined concordia plot for grain W74/2-36, showing the U-Pb results obtained during the two analytical sessions. The inset shows the most concordant data points together with their analysis number (as in Table 1). Error boxes are shown at 1σ.