1

New Treatments for Cancer

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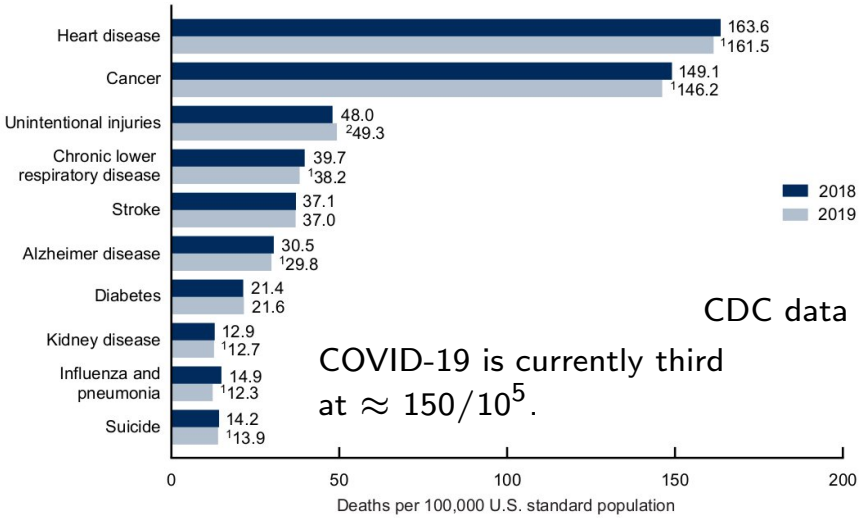

CDC data

COVID-19 is currently third at $\approx 150/10^5$.

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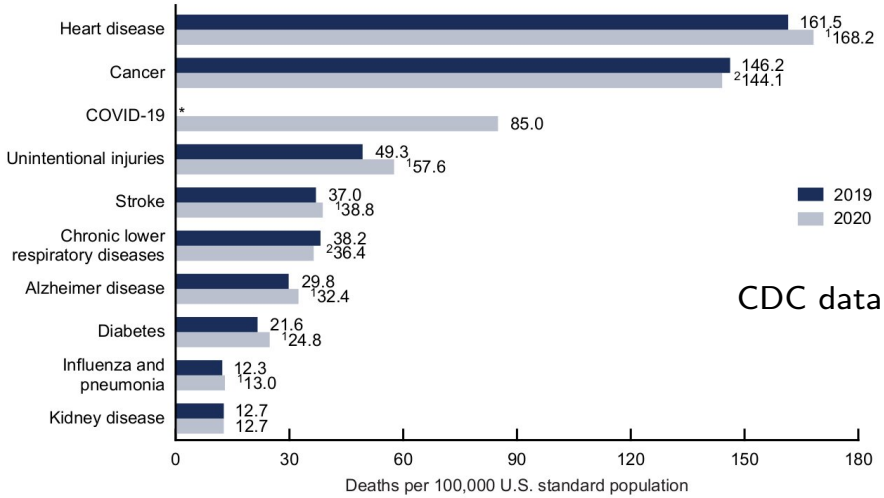

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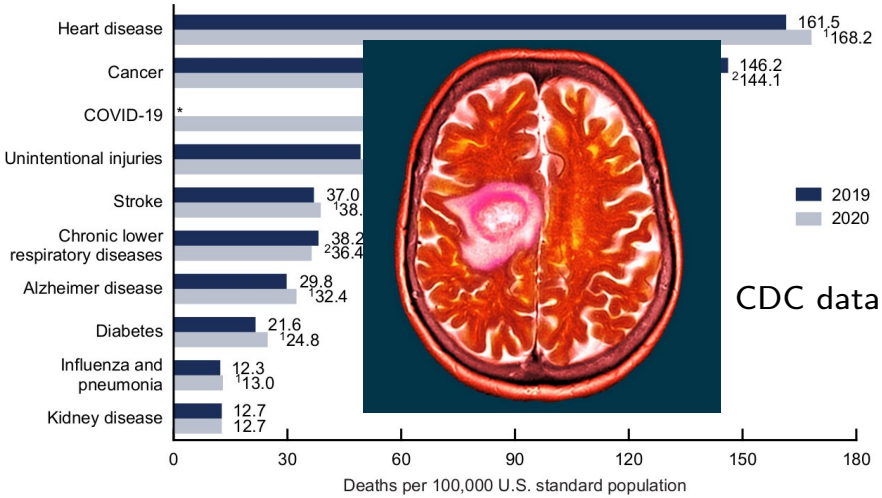

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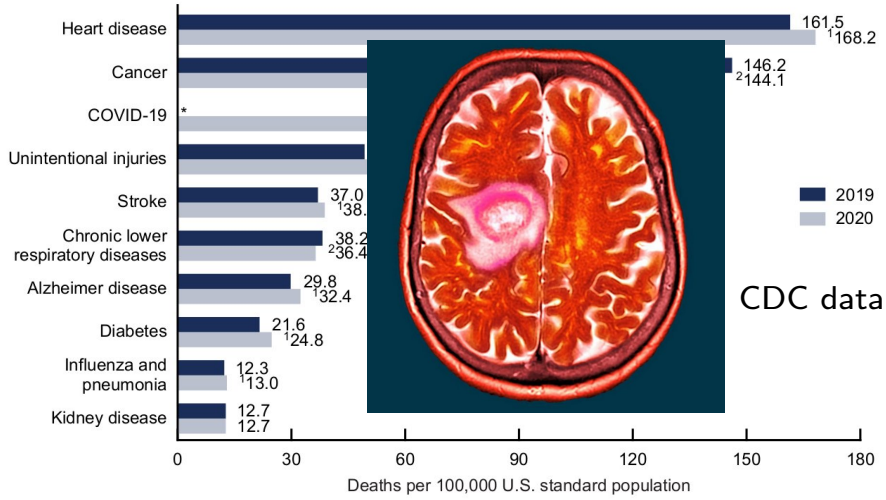

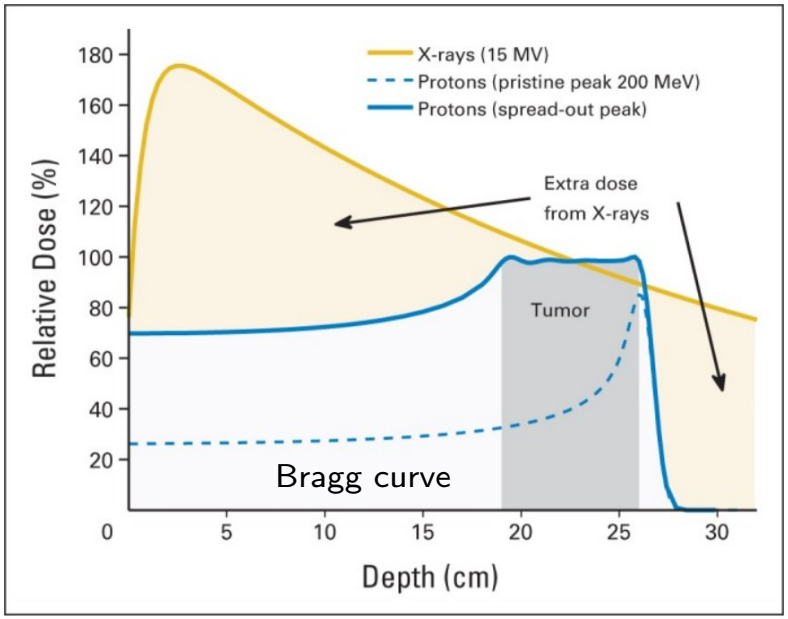

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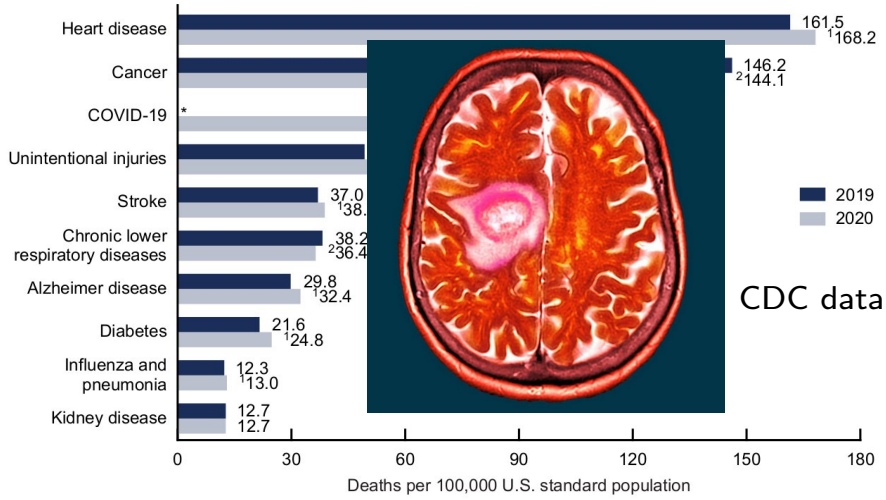

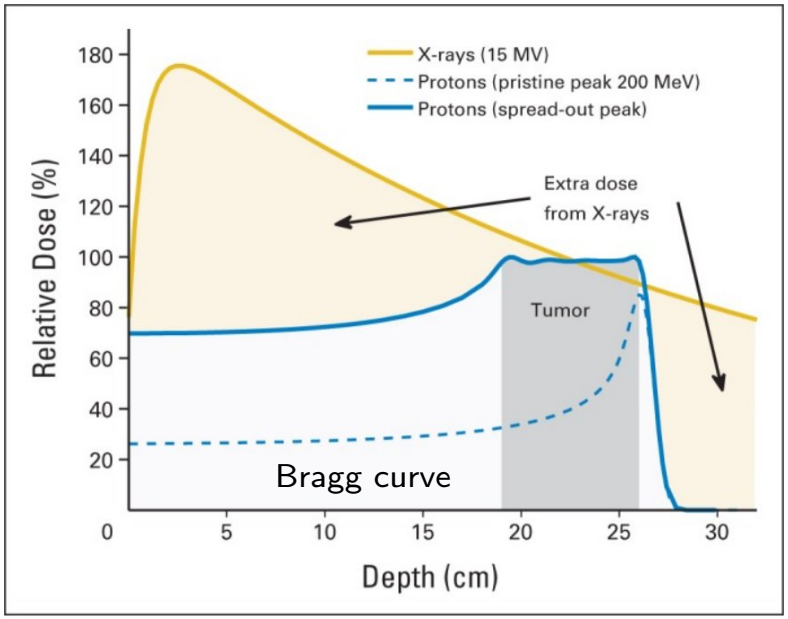

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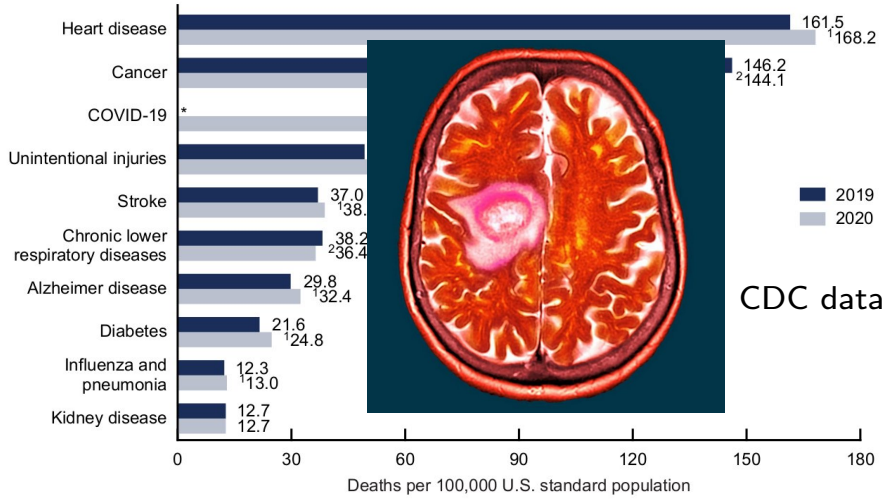
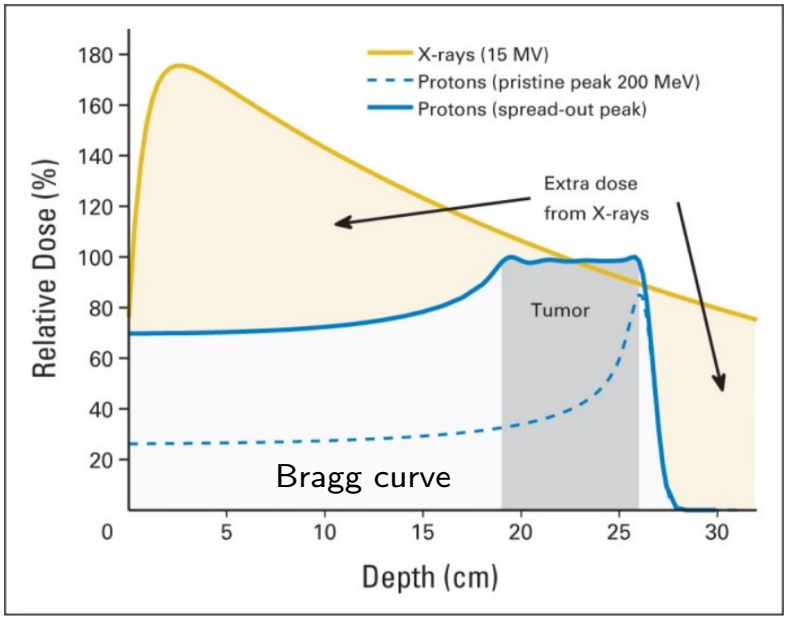
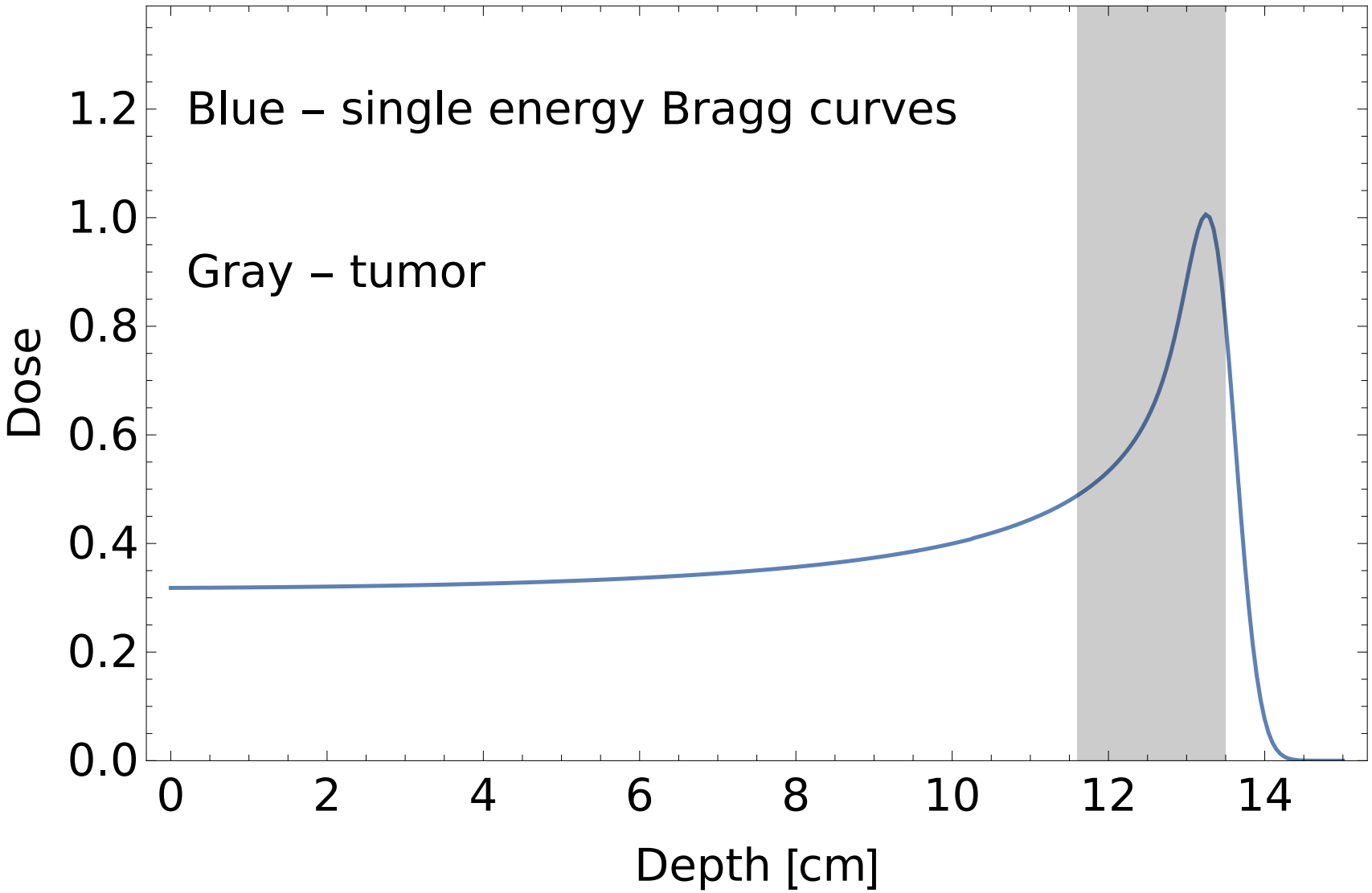




Why Use Protons? 8



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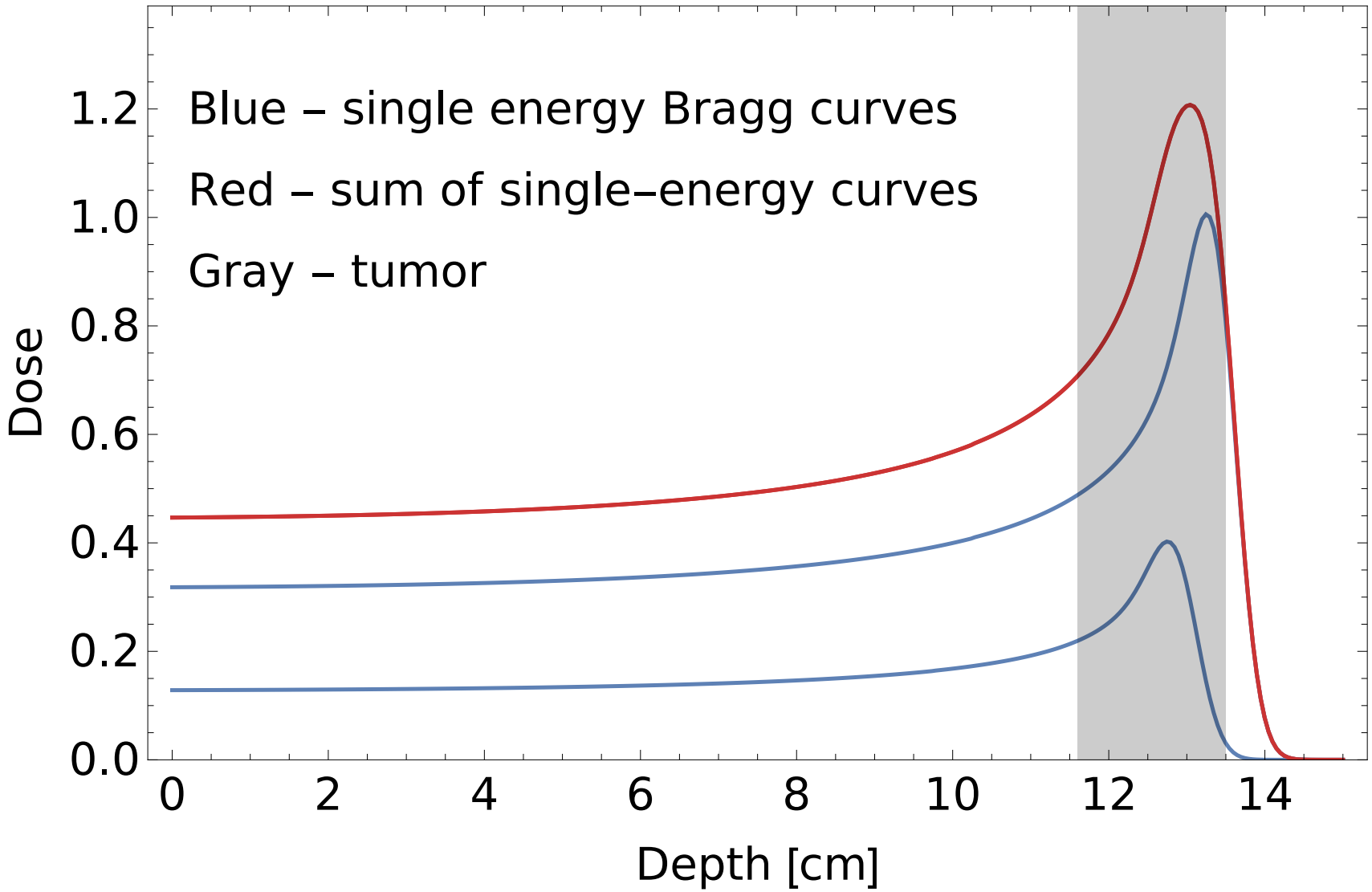
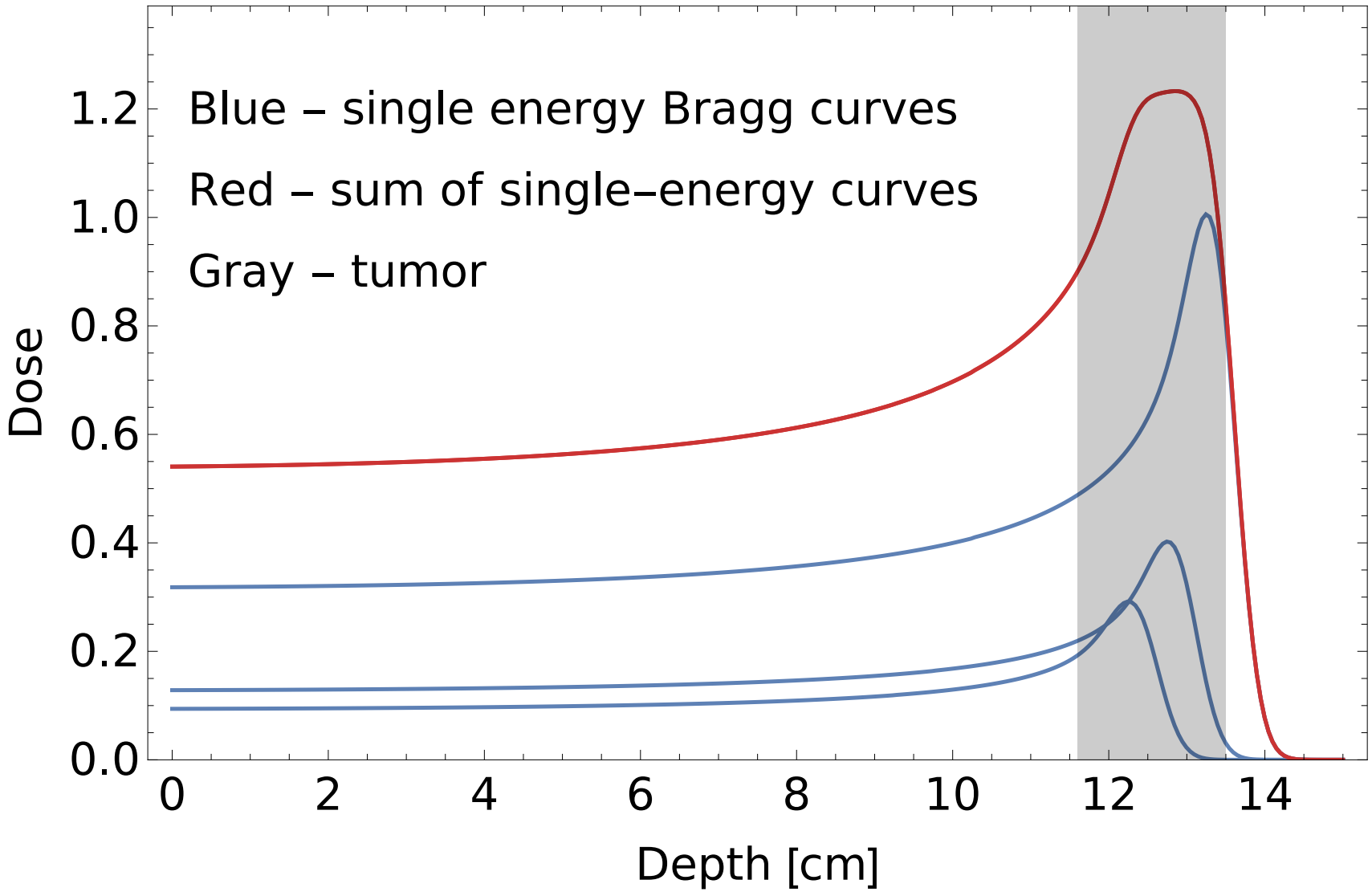
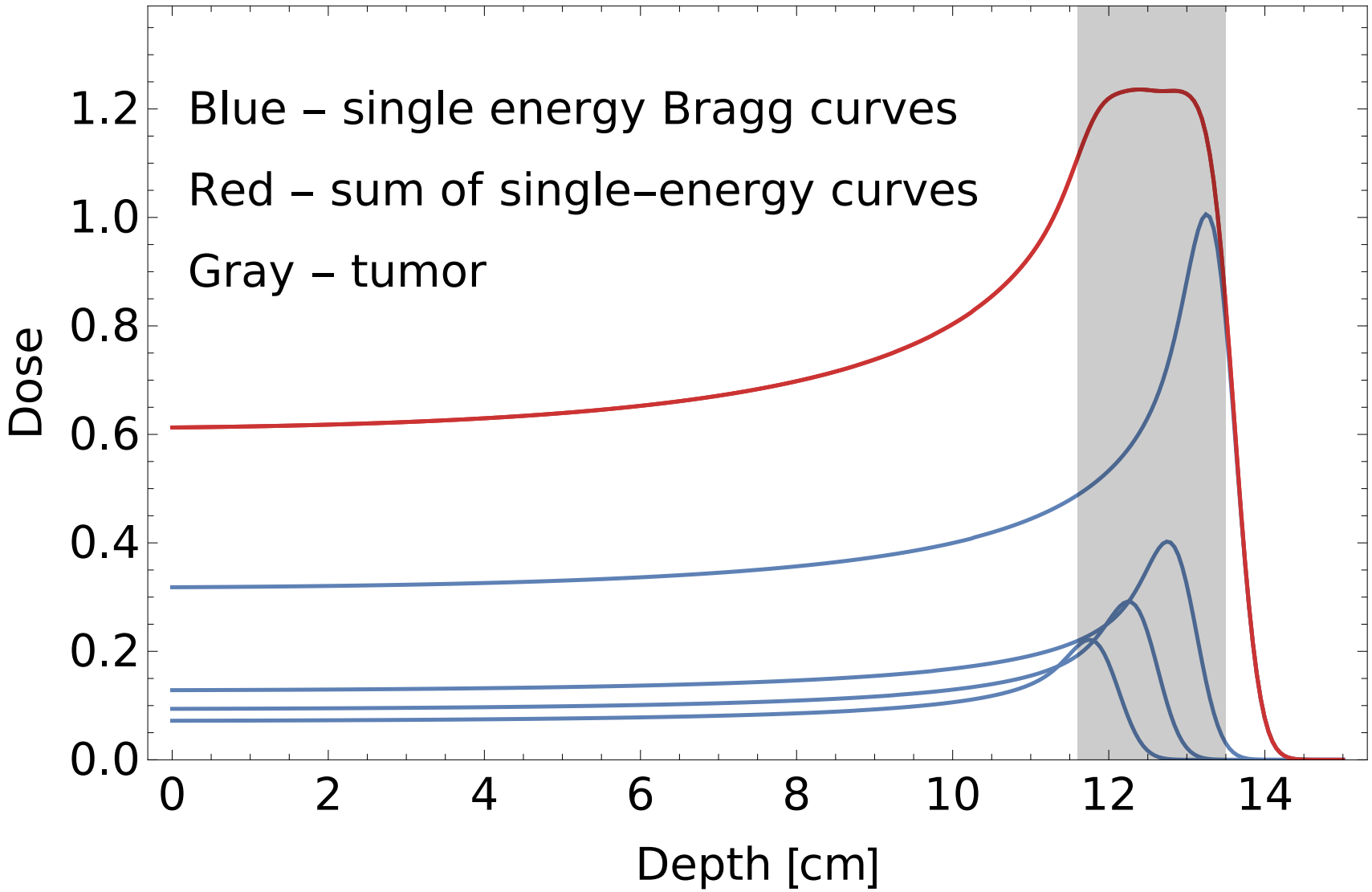



Blue – single energy Bragg curves
Red – sum of single–energy curves
Gray – tumor
Dose
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
2
4
6
8
10
12
14
Depth [cm]

Why Use Protons?



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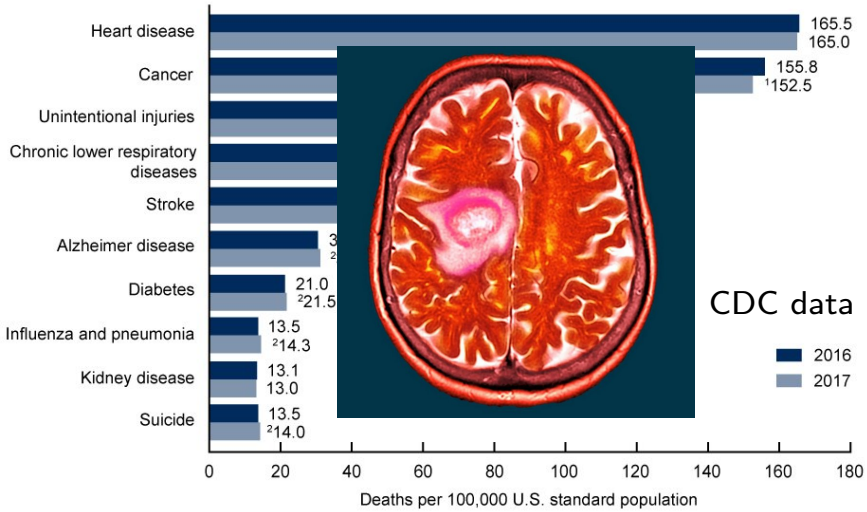
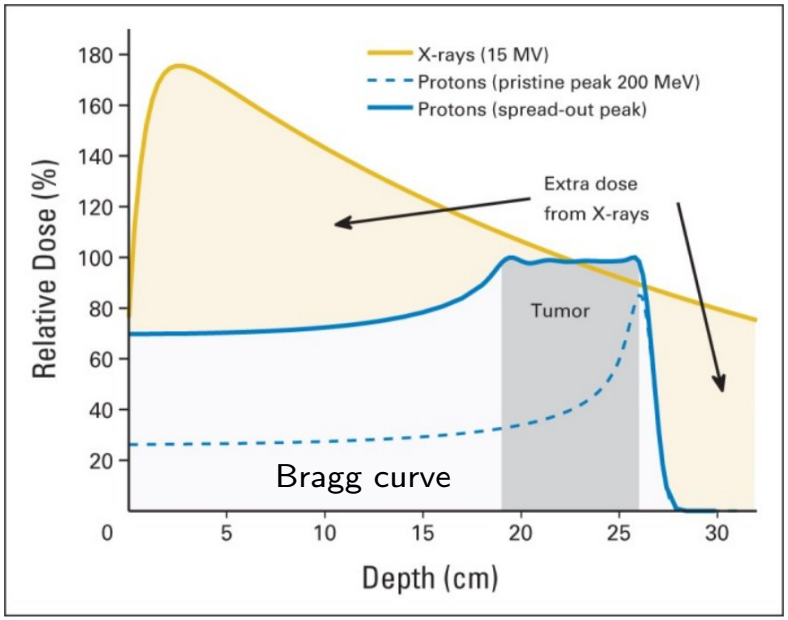
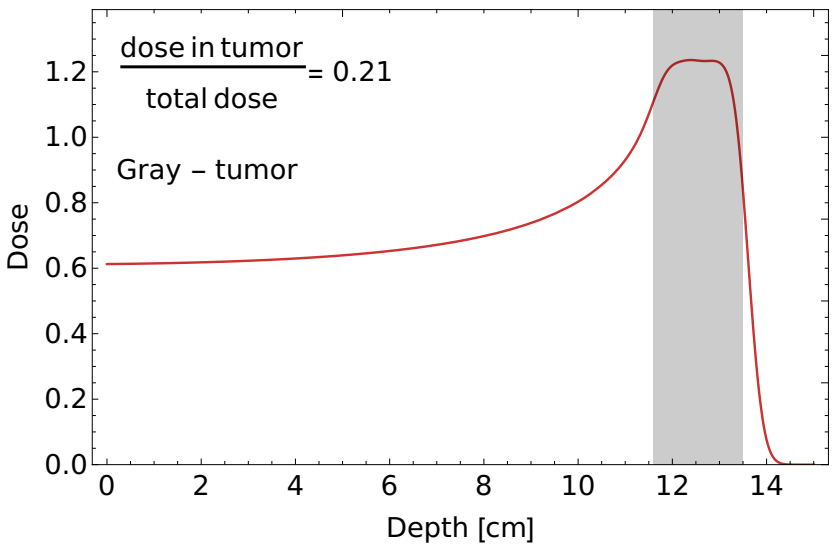
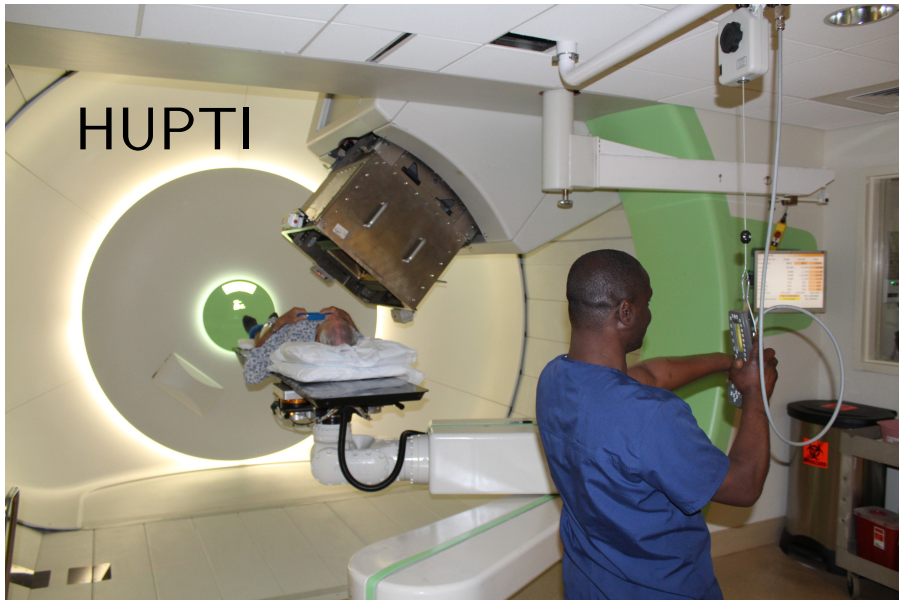


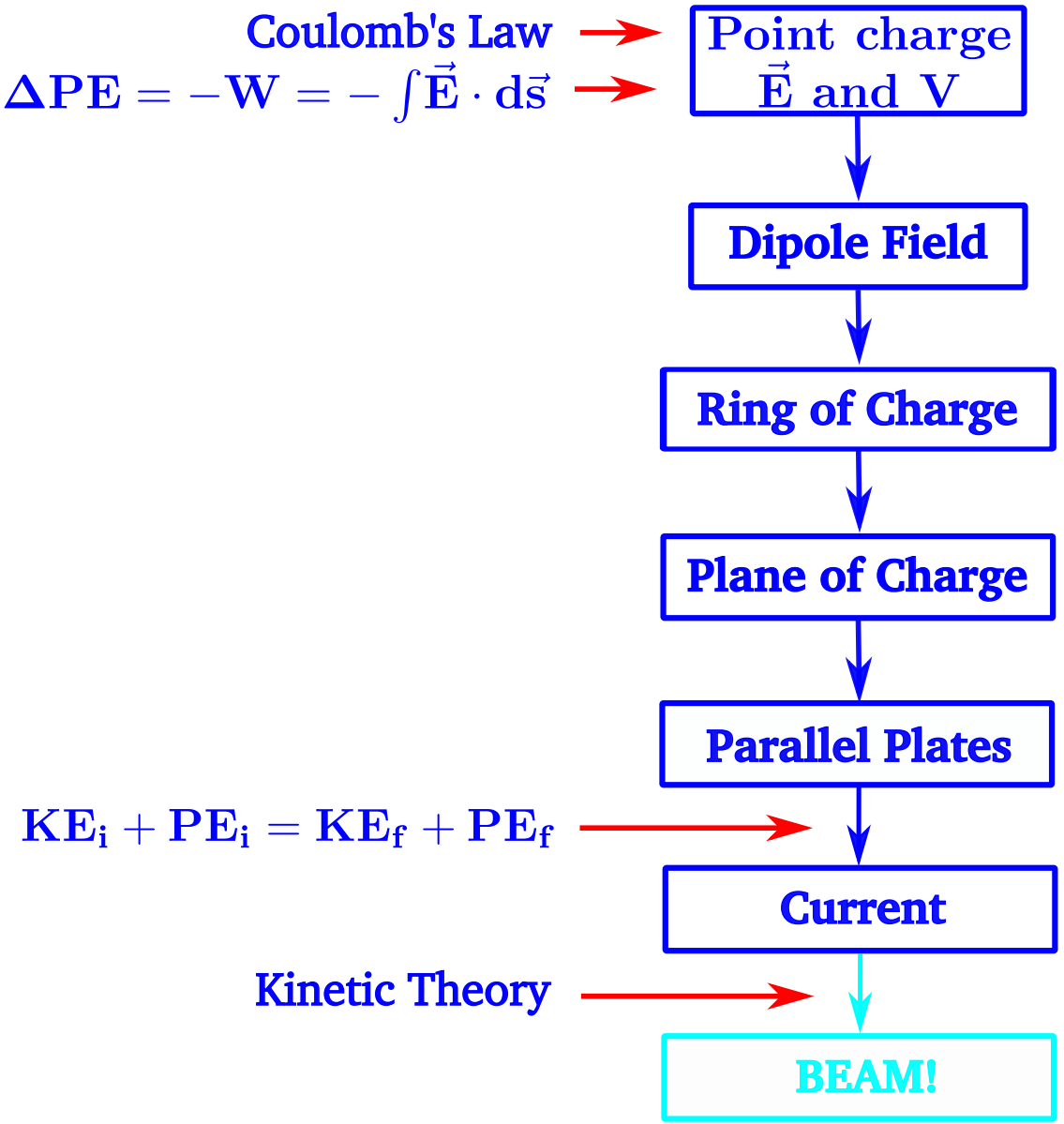


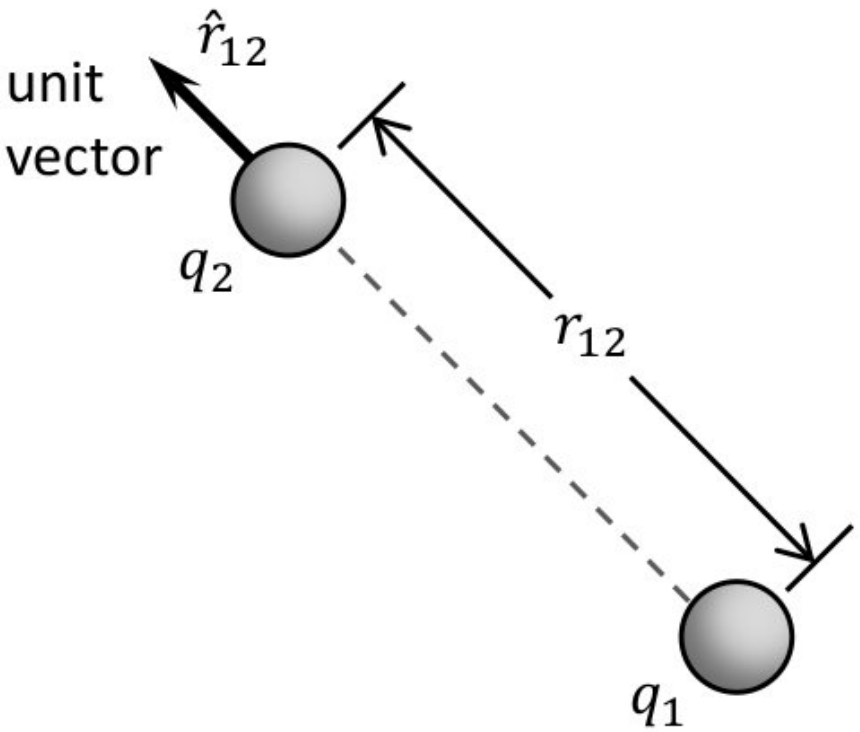
New Treatments for Cancer 13

In proton-beam therapy, high-energy protons are used to kill tumors. In one case an energy $E_{dep} = 200\ J$ must be deposited into the tumor. However, only 21% of the incident proton energy E_{inc} actually goes into the tumor. To create the beam, protons are accelerated from rest through an electric potential difference $V_p = 100\ MV = 10^8\ V$. The total exposure time is to be three minutes. What is the electric current during the treatment? If the beam spot is circular with radius $r = 0.1\ m$, what is the beam proton density? Compare this with the proton density of water ($\approx 10^{28}\ m^{-3}$).






Coulomb's Law
$\Delta PE = -W = -\int \vec{E} \cdot d\vec{s}$
Point charge
$\vec{E}$ and V
Dipole Field
Ring of Charge
Plane of Charge
Parallel Plates
$KE_i + PE_i = KE_f + PE_f$
Current
Kinetic Theory
BEAM!



$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

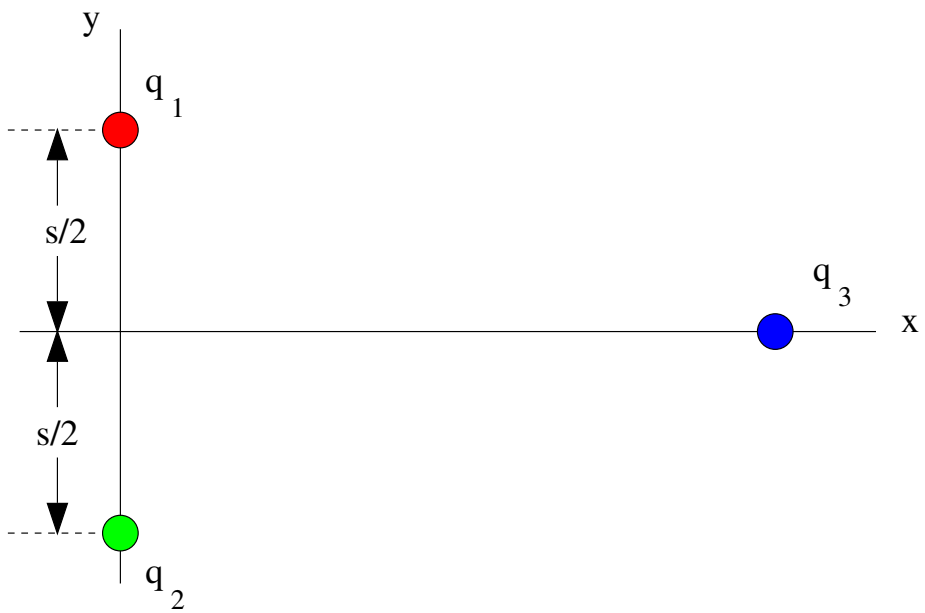
$$k_e = 8.99 \times 10^9 \ \mathrm{N\,m^2/C^2}$$

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 magnitude and direction of the electrical force between the two particles? Compare the electrical force with the gravitational force $F_G = 3.6 \times 10^{-47}\ N$.

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

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 s. What is the electric field at the position of charge 3 due to the other charges? Demo here.

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



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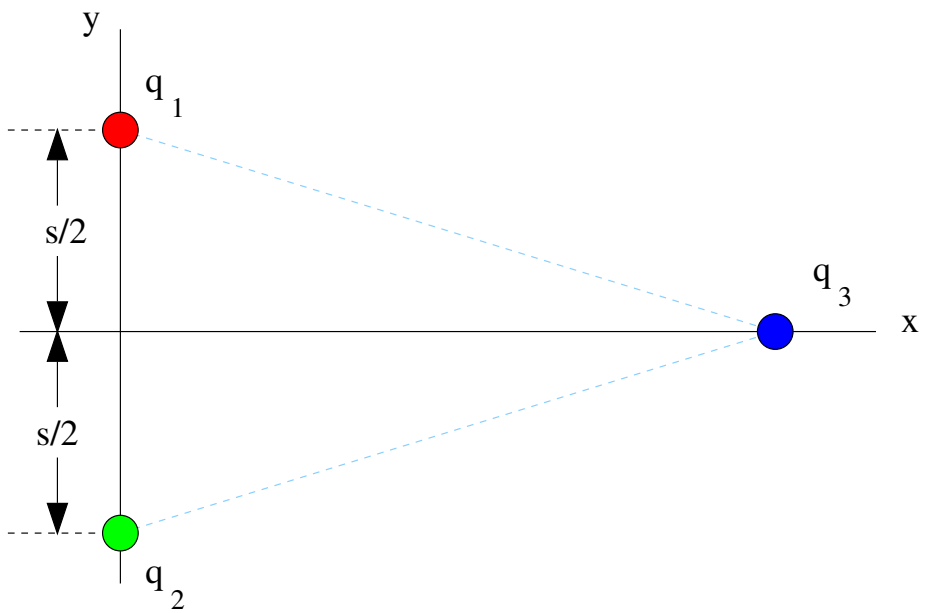

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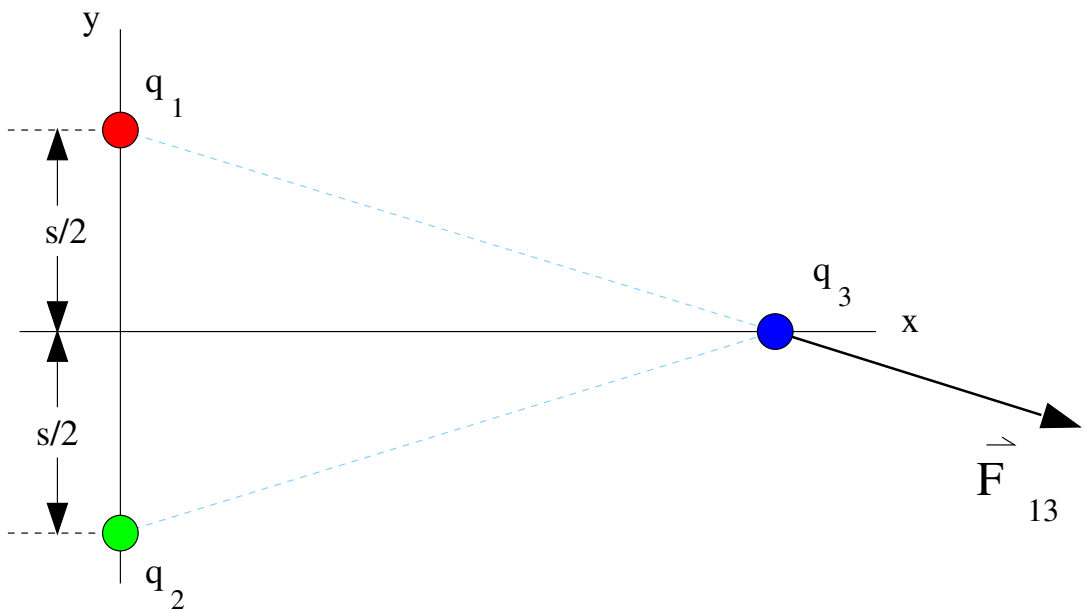

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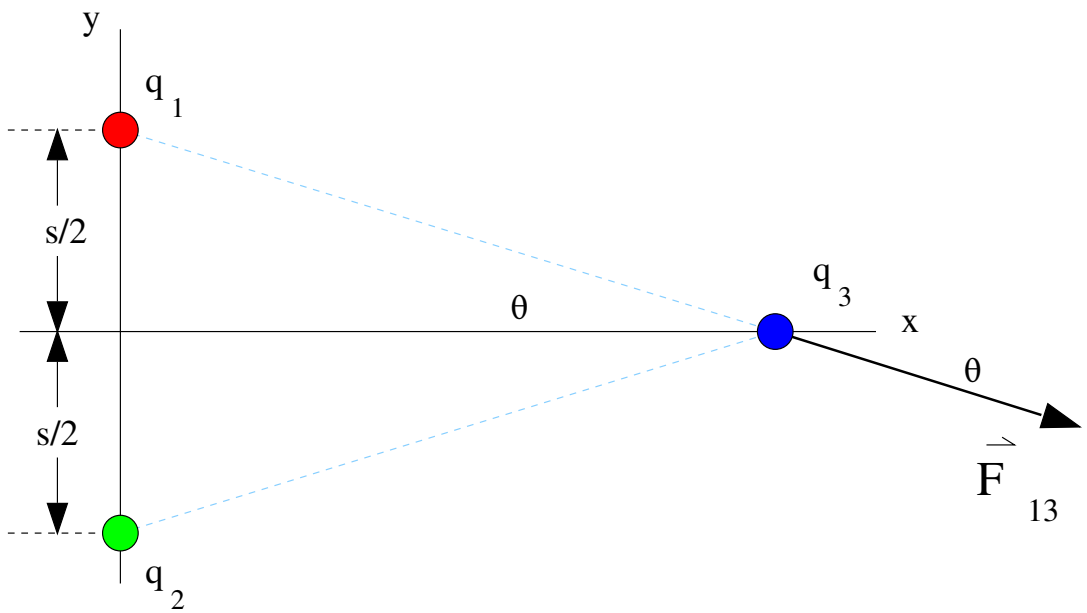

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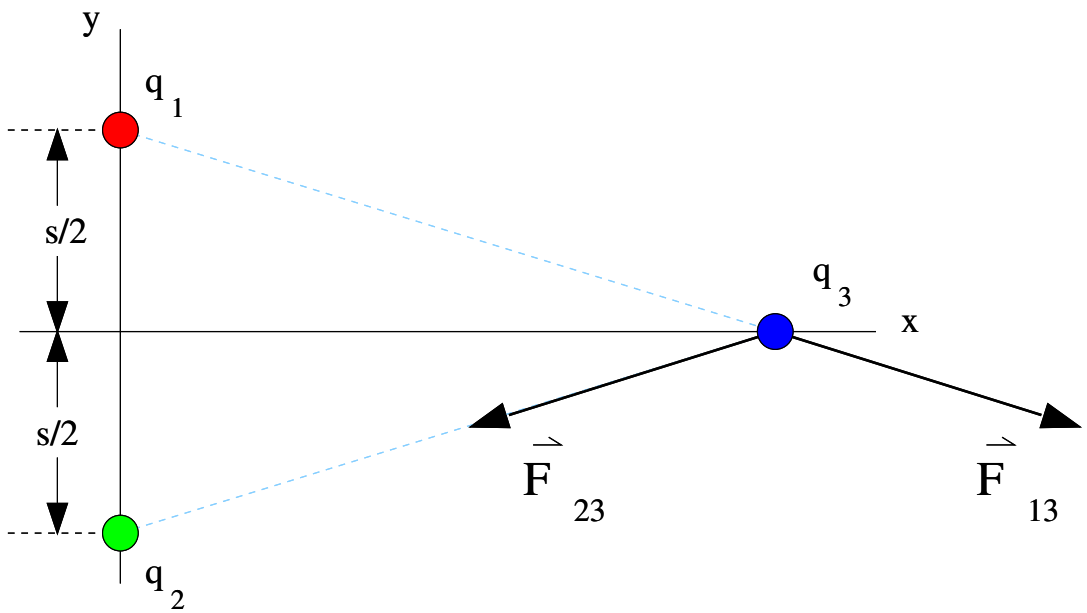

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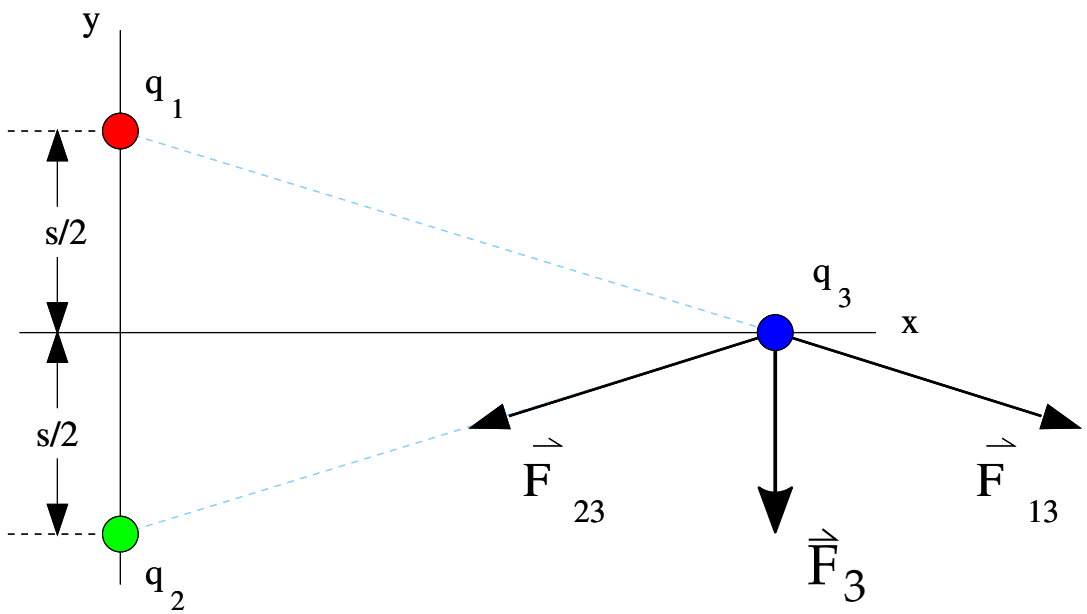

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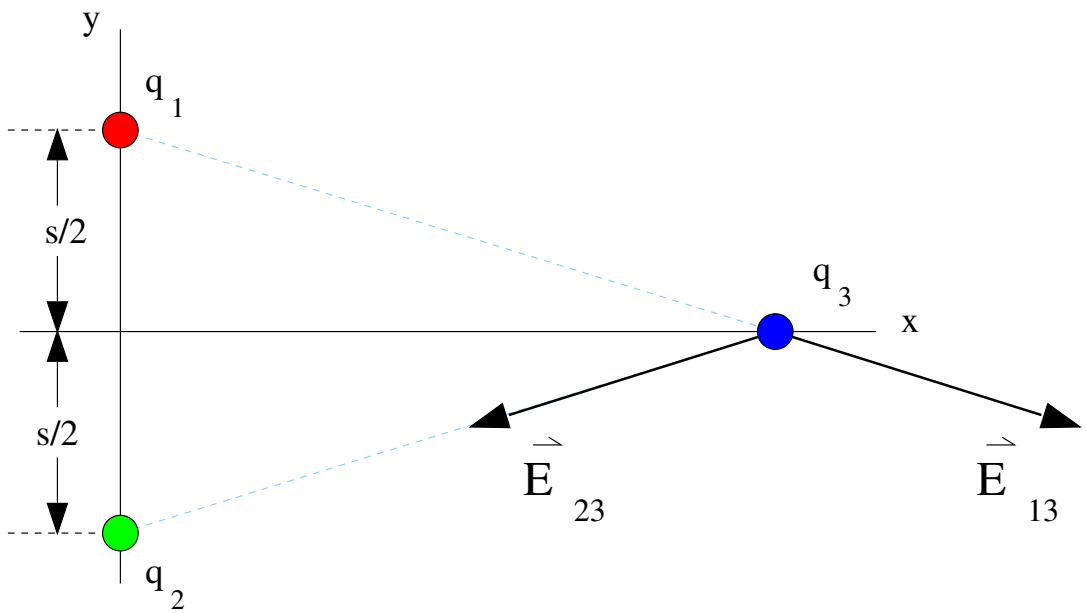

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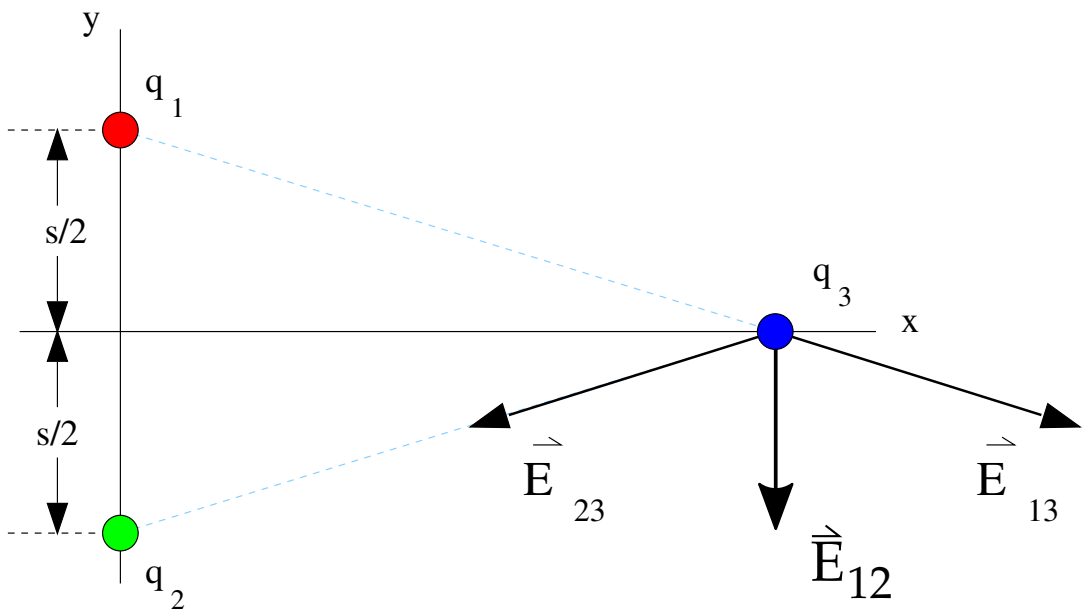
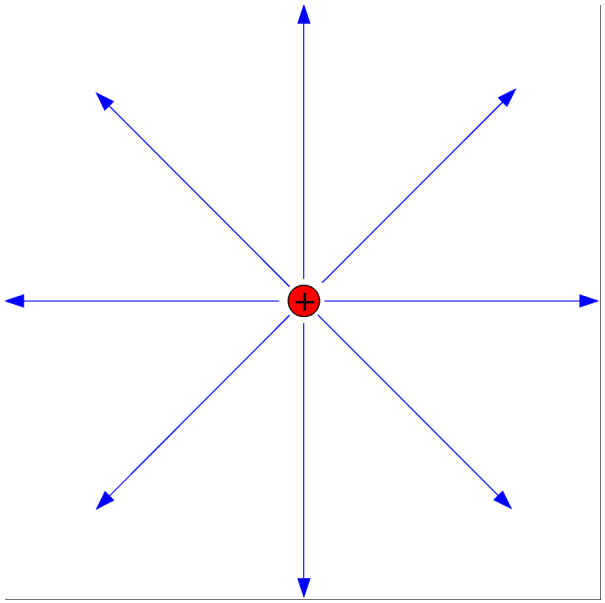
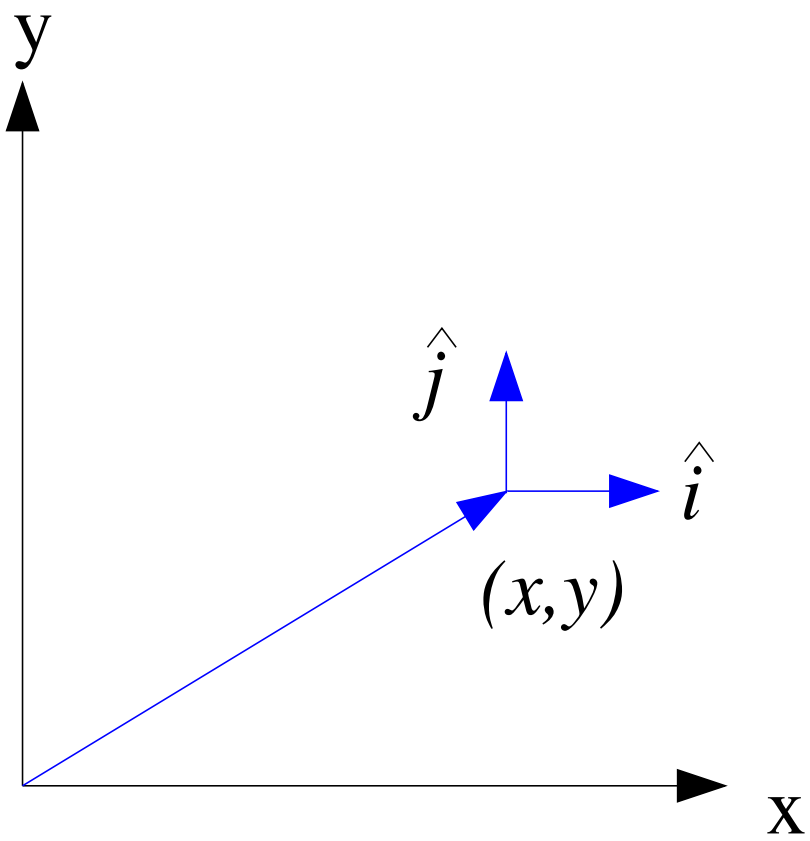
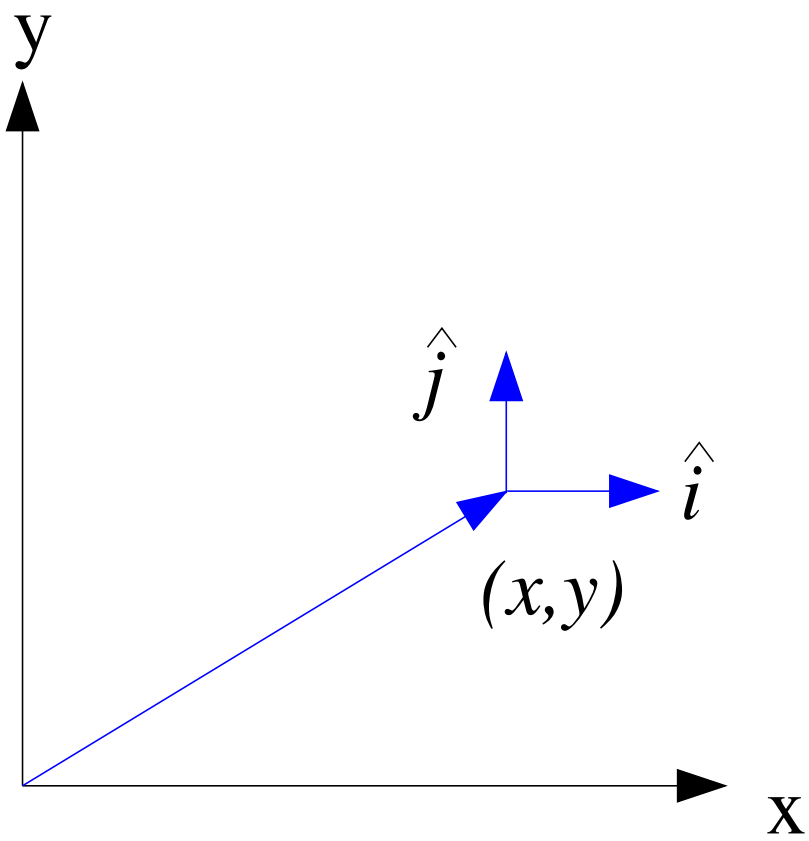


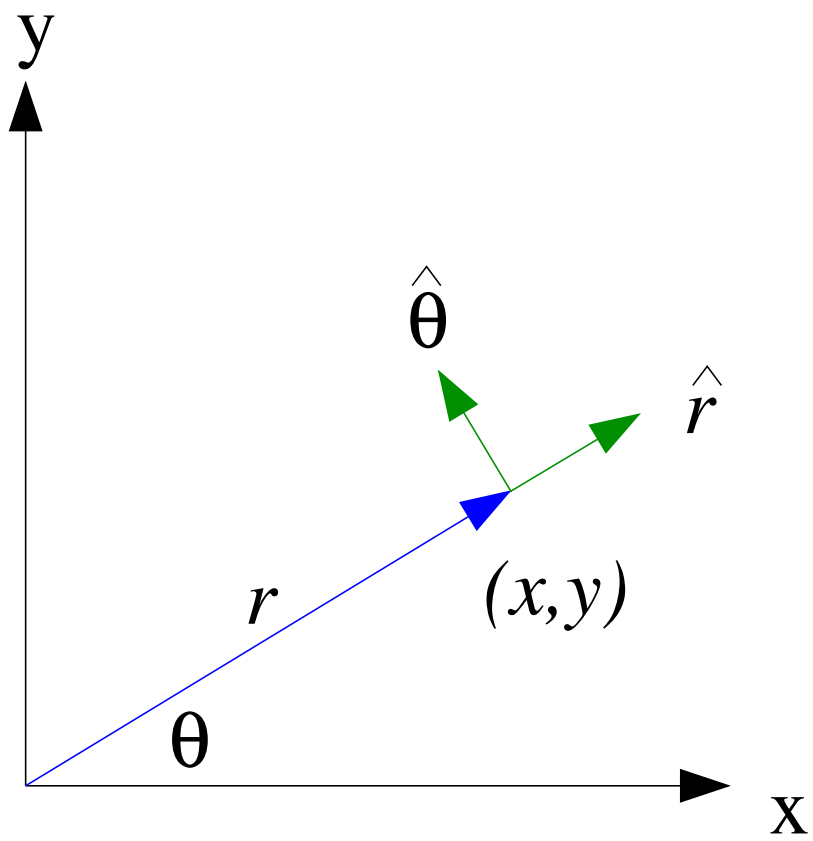
The Electric Potential of a Point Charge - 1 25

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. Demo here.

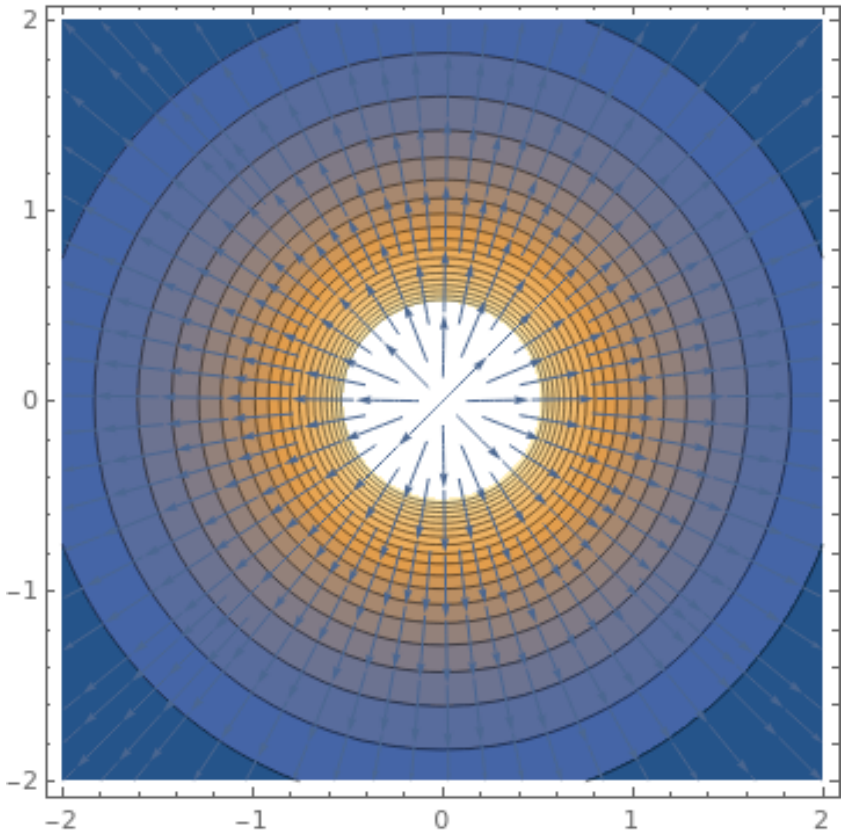


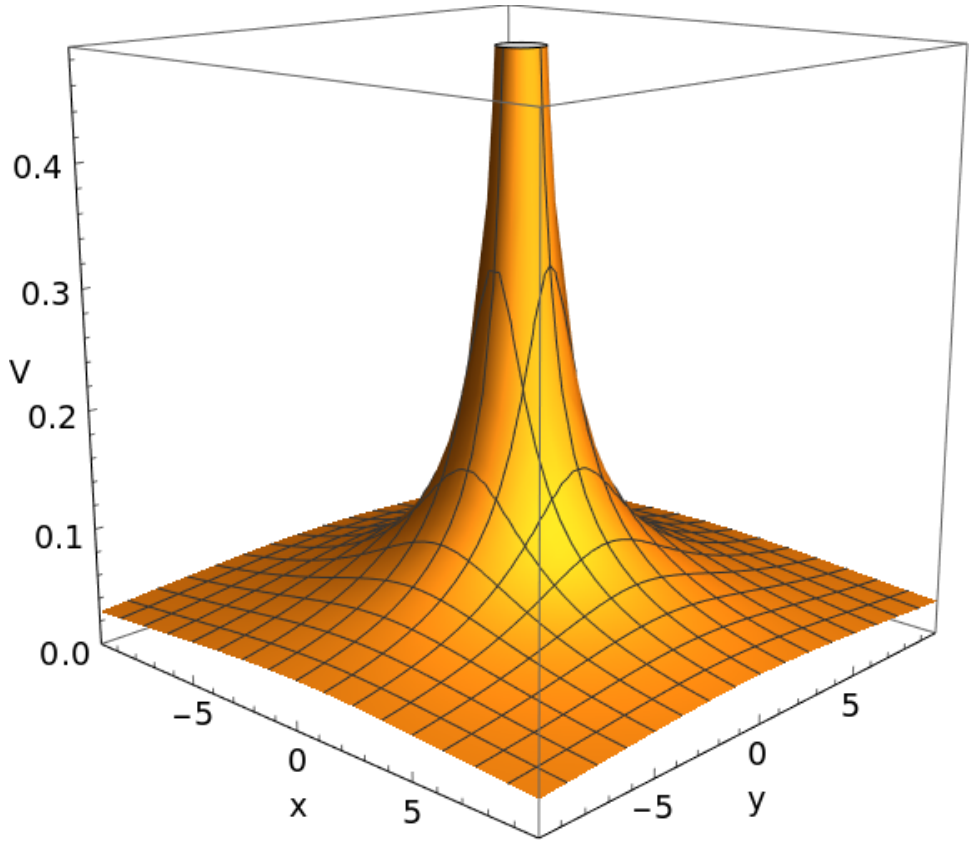

y
$\hat{j}$
$\hat{i}$
(x,y)
x

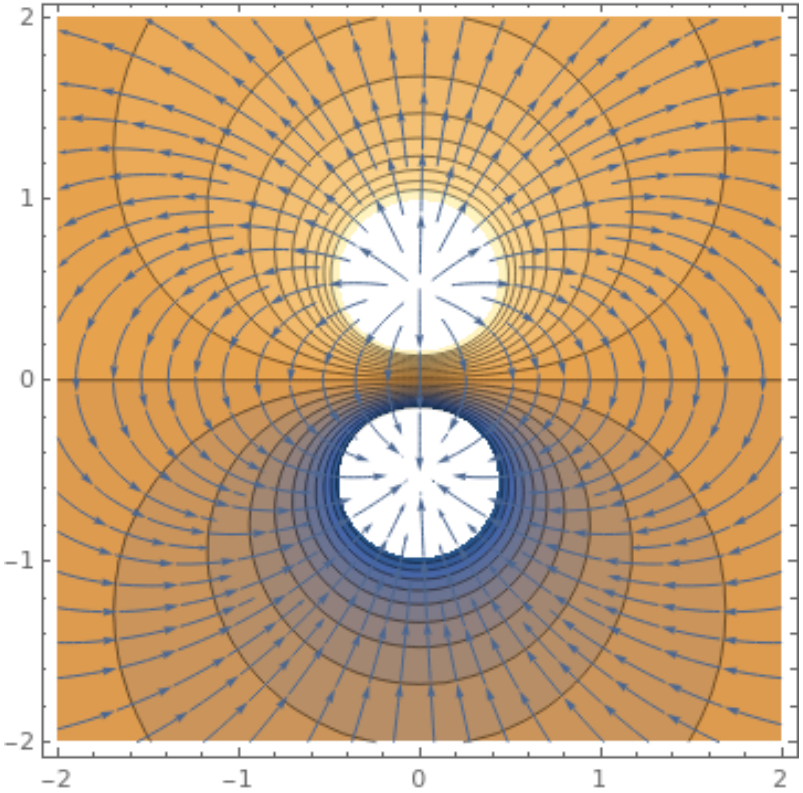

y
x
$\hat{j}$
$\hat{i}$
(x,y)

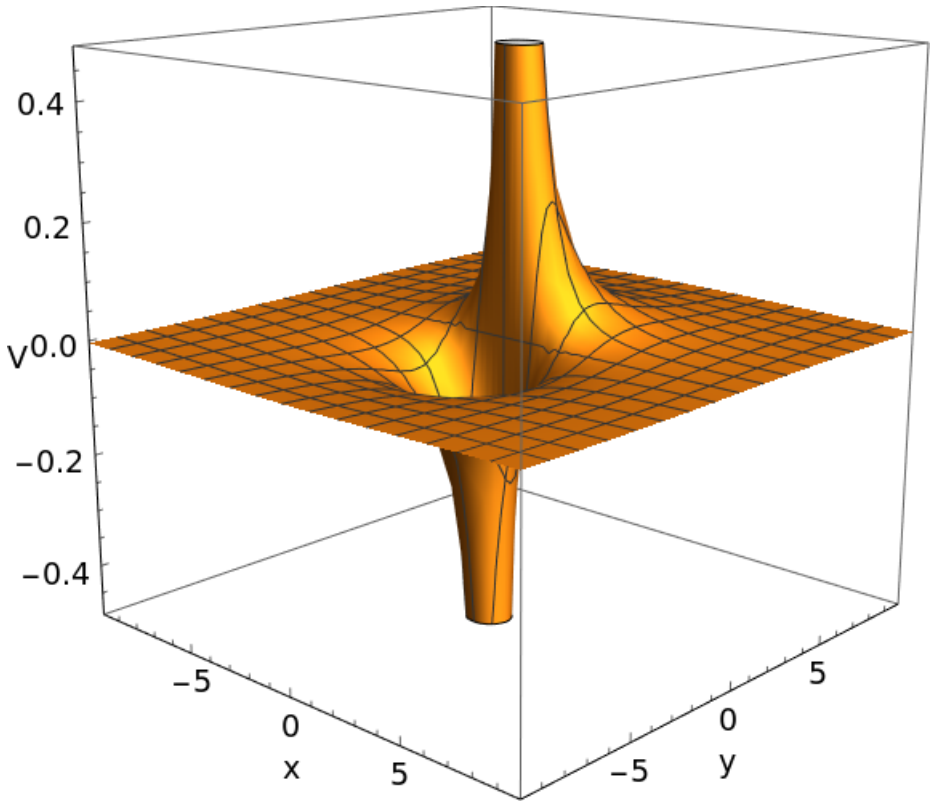

y
x
$\hat{\theta}$
$\hat{r}$
r
θ
(x,y)

The Electric Potential of a Point Charge - 3

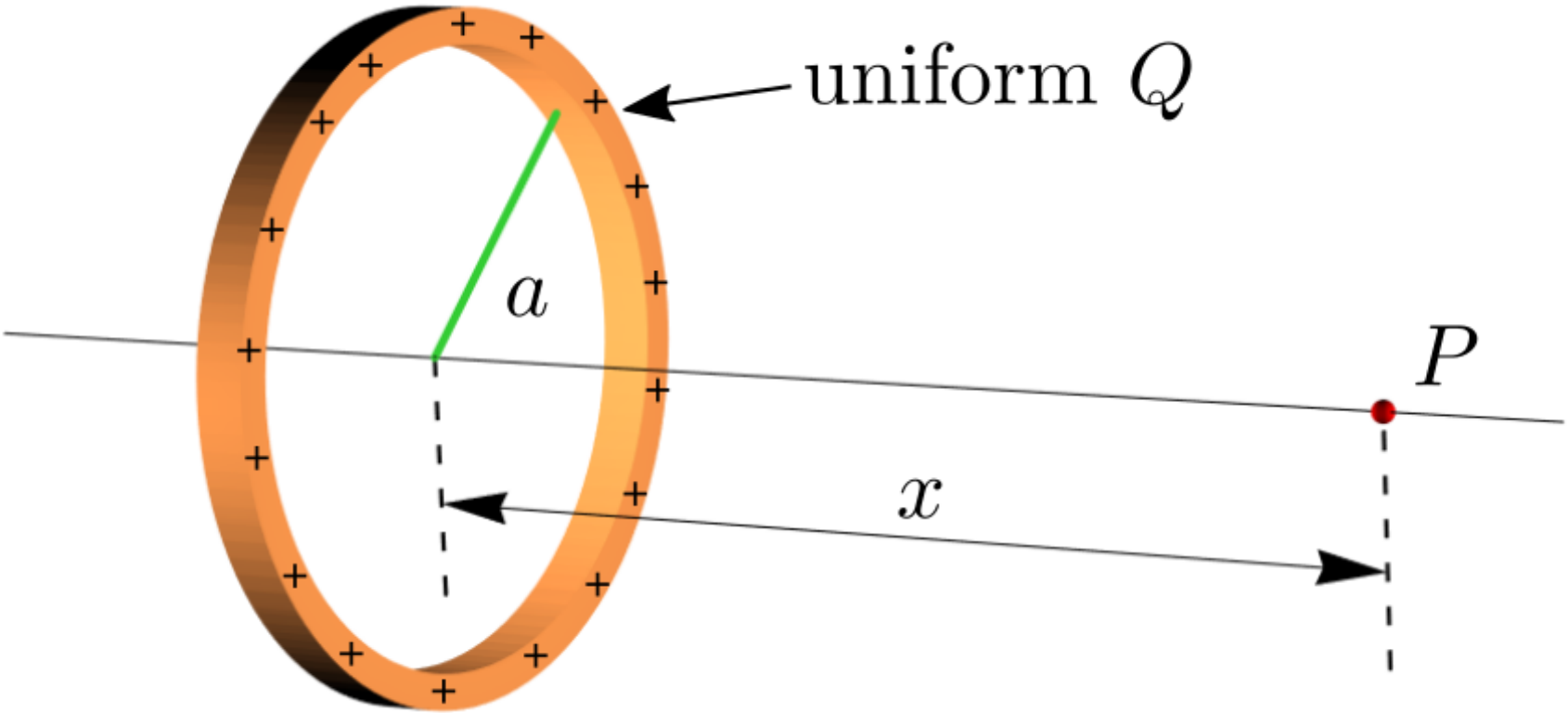


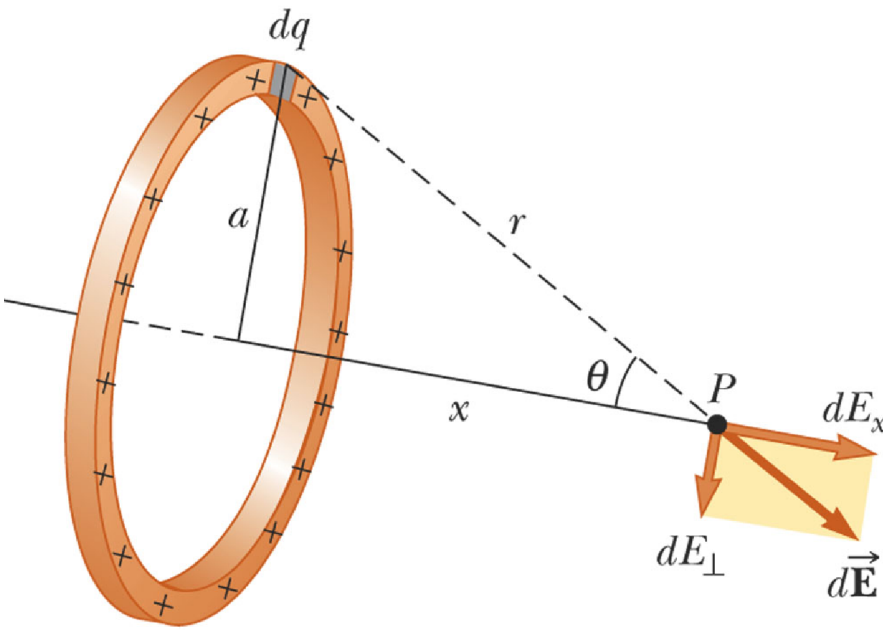



2
1
0
−1
−2
−2
−1
0
1
2

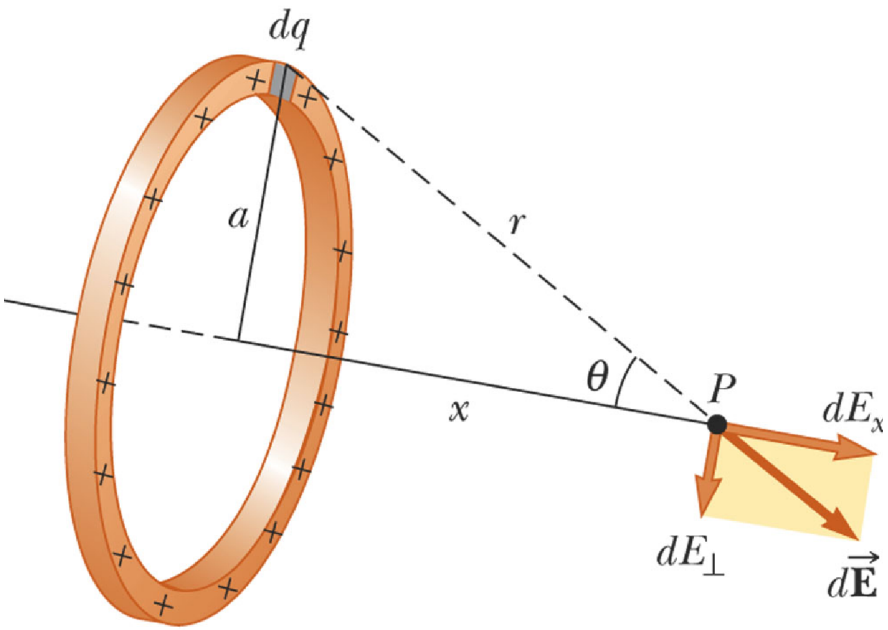

0.4
0.2
V 0.0
−0.2
−0.4
−5
0
x
5
−5
0
y
5

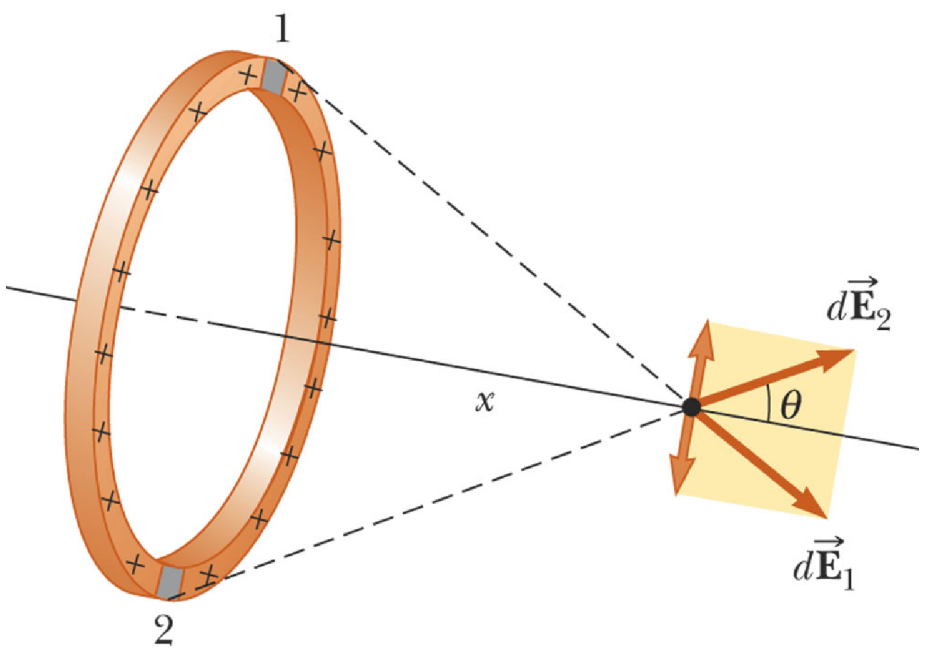
A ring of radius a as shown in the figure has a positive charge distribution per unit length with total charge Q. Calculate the electric field $\vec{E}$ along the axis of the ring at a point lying a distance x from the center of the ring. Get your answer in terms of a, x, Q.



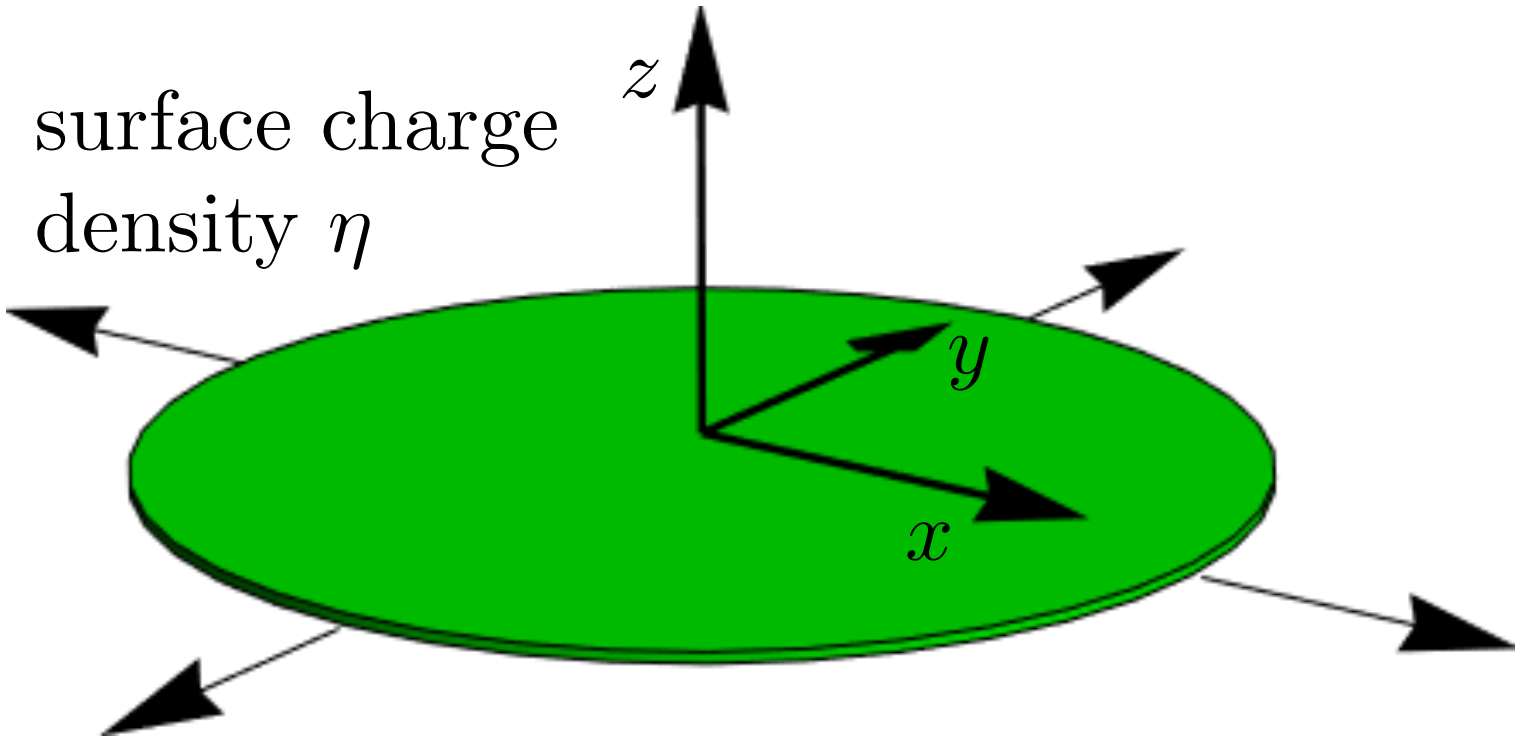

dq
a
r
θ
x
P
dE_x
dE⊥
dE

The Charged Ring





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



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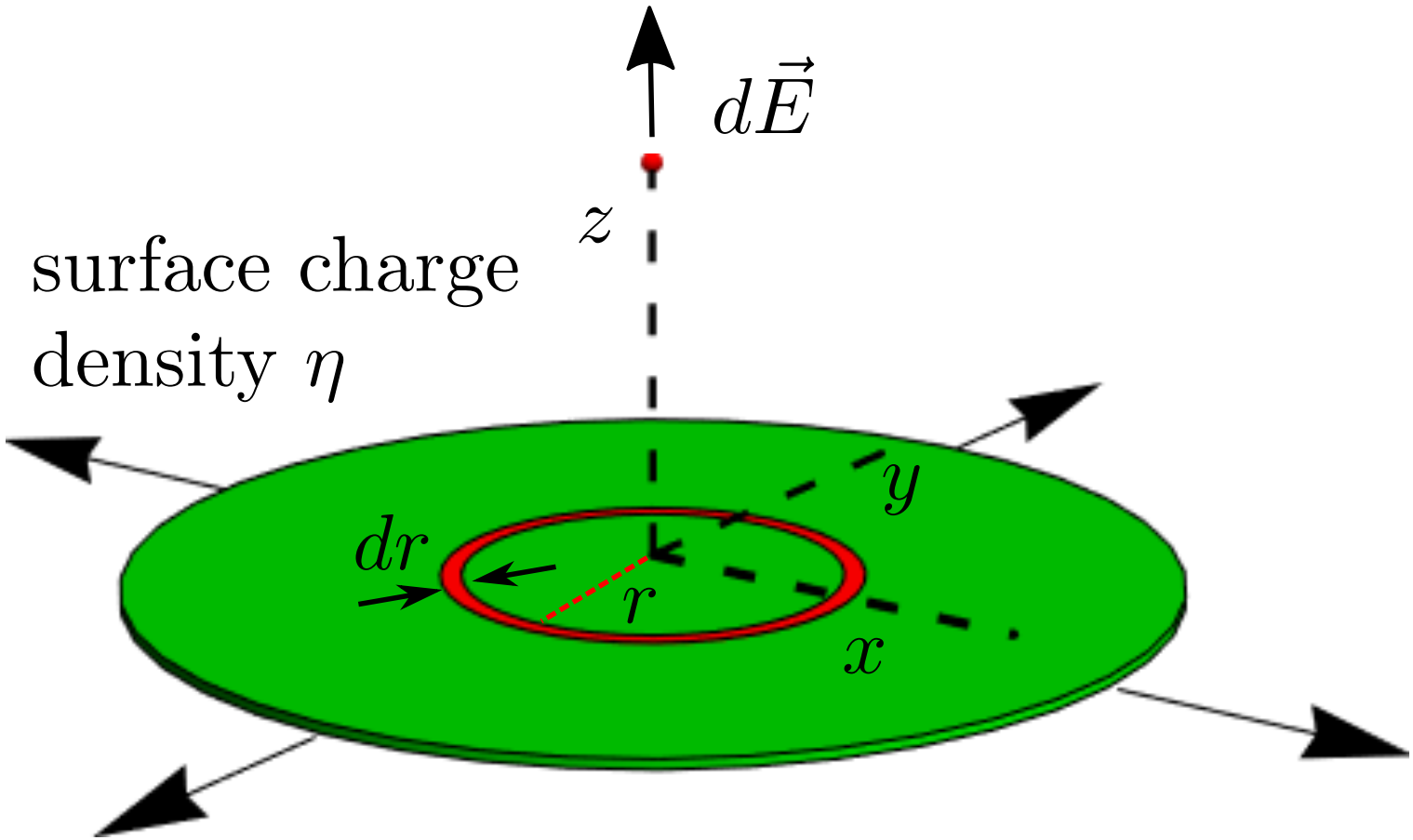
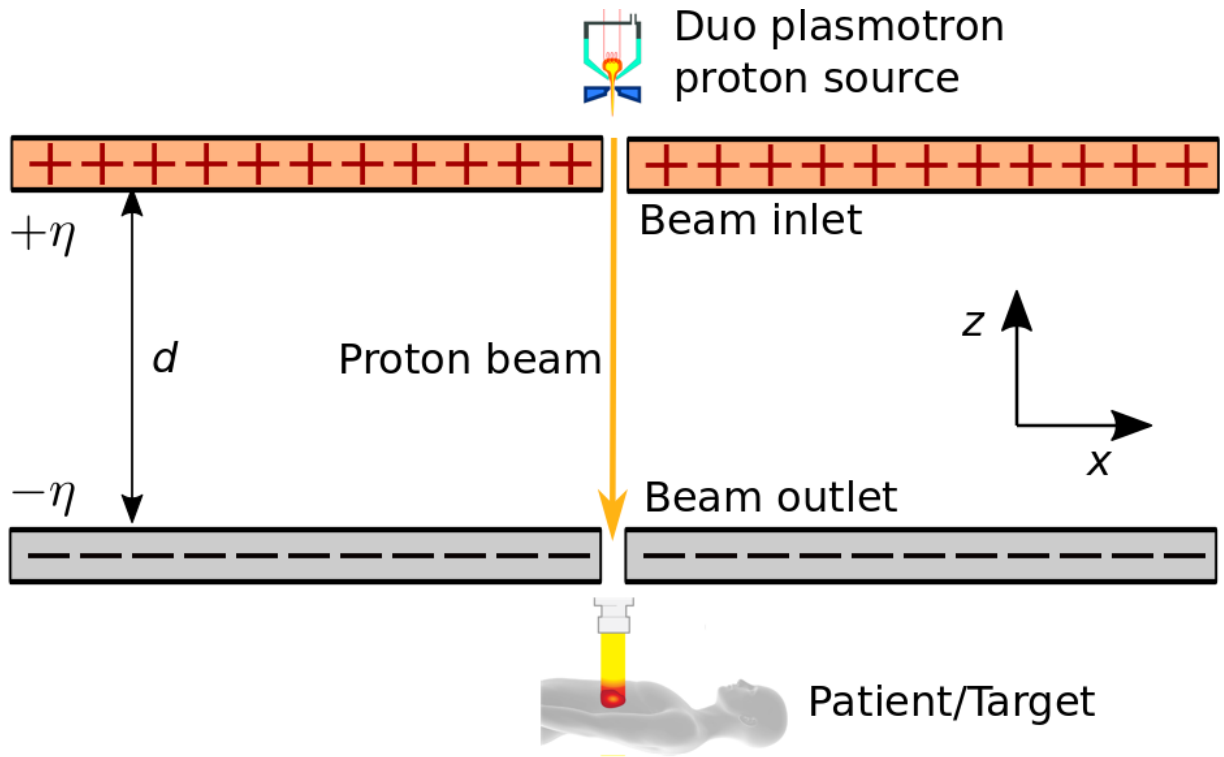
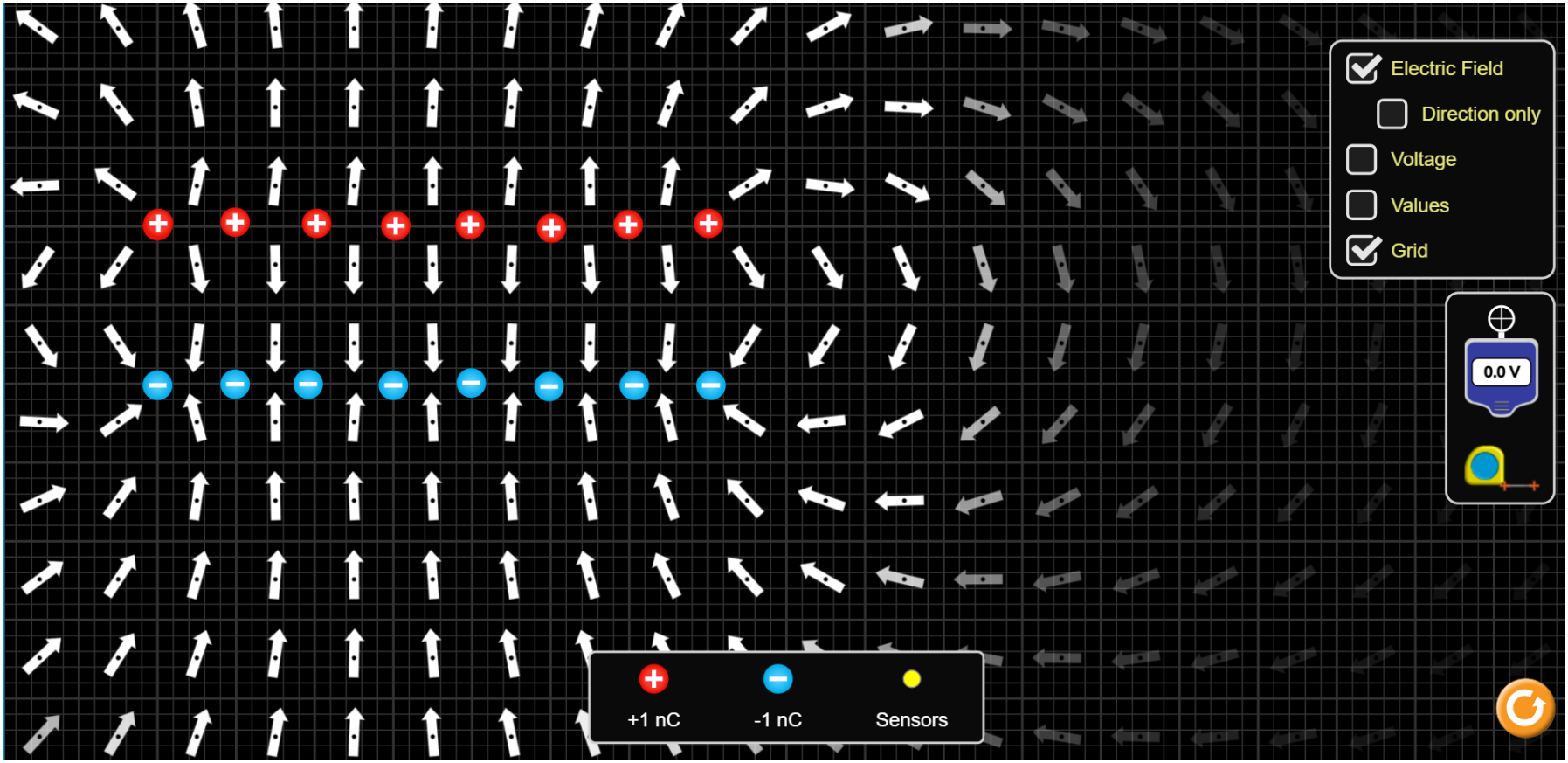


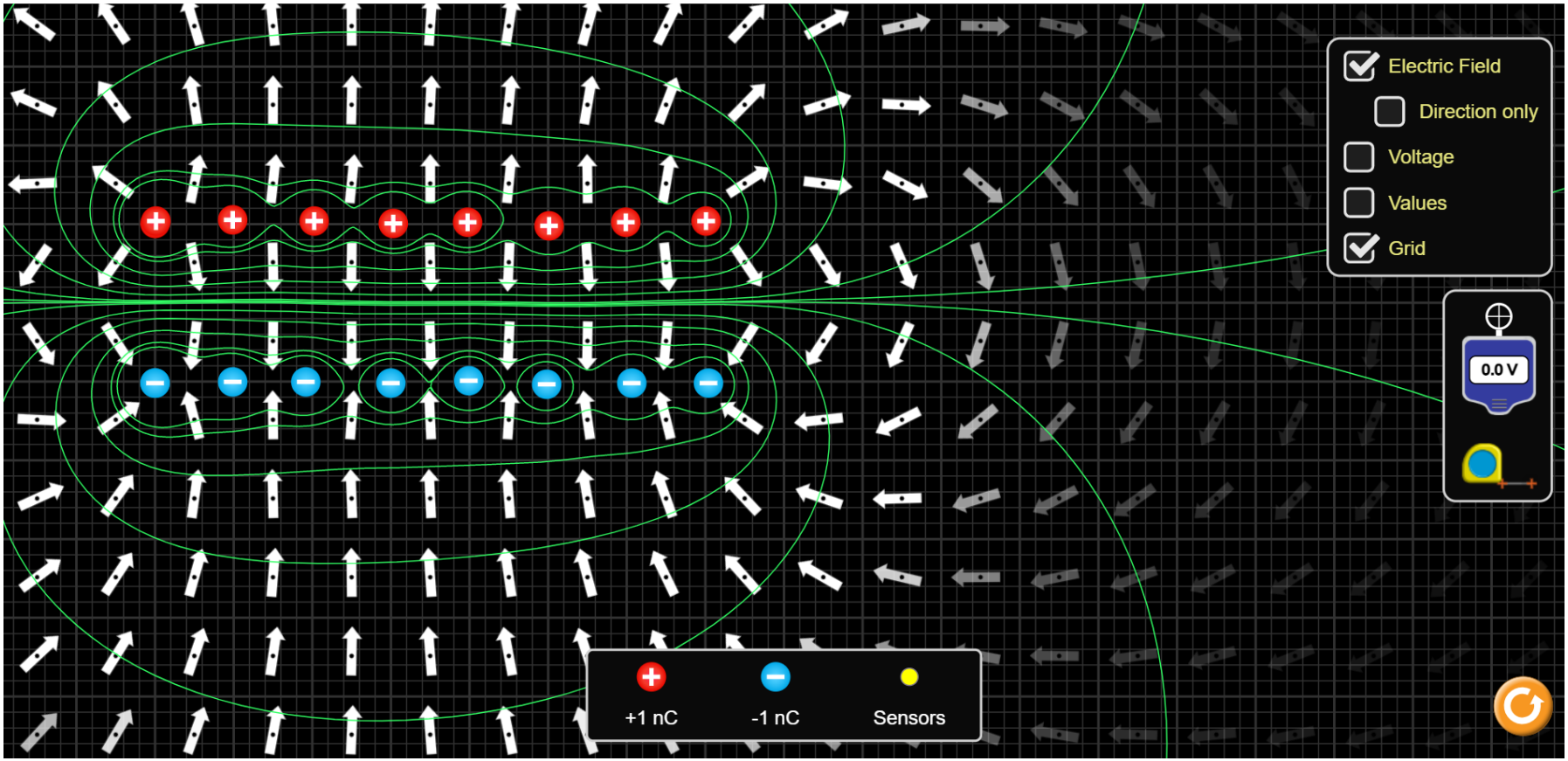
To create a particle beam for cancer therapy protons are injected at low velocity between two large, metal plates with surface charge densities $\pm\eta$ and separated by a distance d. The particles speed up as they cross between the plates. What is the field between the plates? What is the electric potential across the plates in terms of the η and d? What is the proton velocity after it leaves the accelerator?

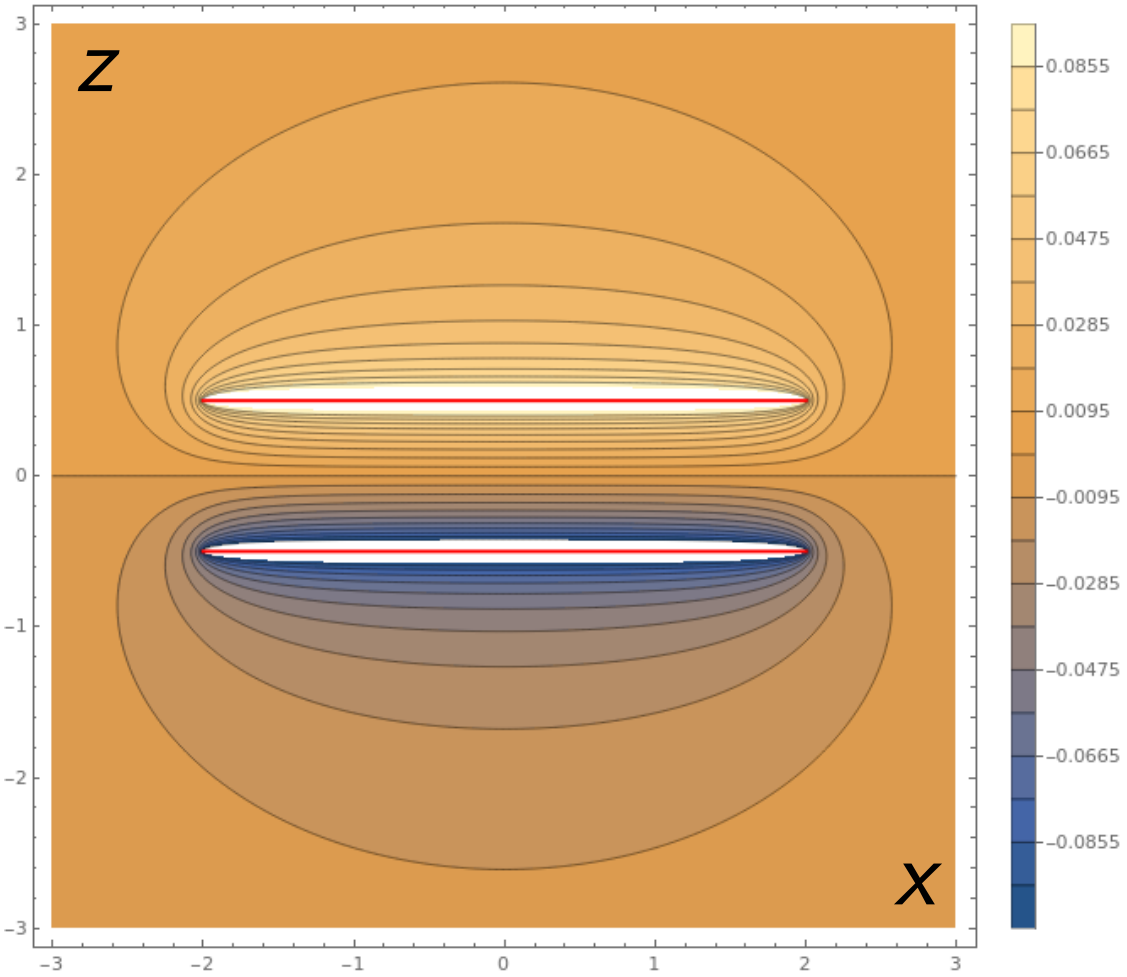
$d = 0.1\ m$
$\eta = 8.85 \times 10^{-8}\ C/m^2$



The Parallel Plate Electric Potential and Field 36

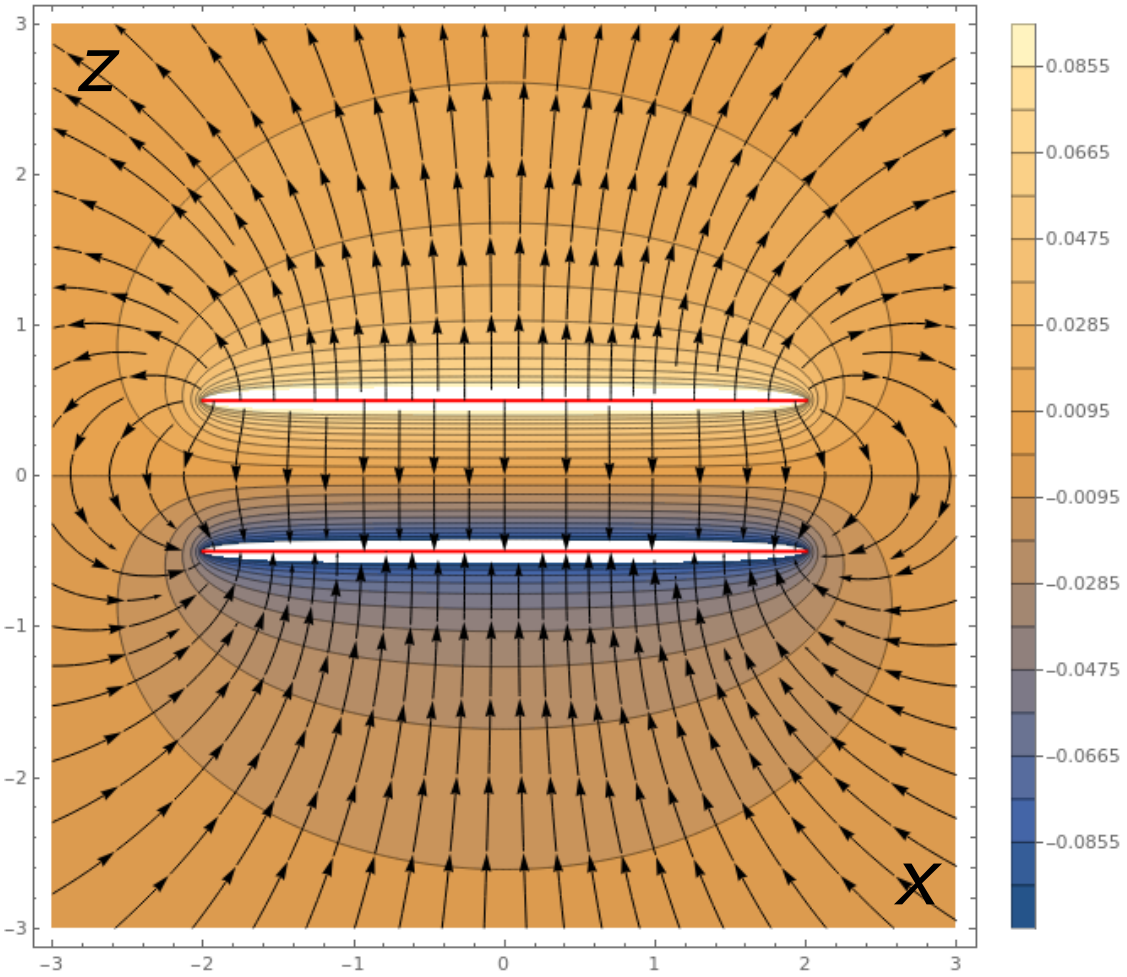



Electric Field
Direction only
Voltage
Values
Grid
0.0 V
+1 nC
-1 nC
Sensors



- Contours represent values of fixed electric potential - equipotentials.
- Colors also represent the value of the electric potential. See legend.
- White means the plot reached the upper or lower limit.
- Top plate (red) - positive, forms a ridge.
- Bottom plate (red) - negative, forms a valley.
- Electric field lines come out of positive charges (upper plate).
- And go into negative charges (bottom plate).
- Field lines are prependicular to equipotentials.

Units of electric potential (y direction out of the plane) are V/C.



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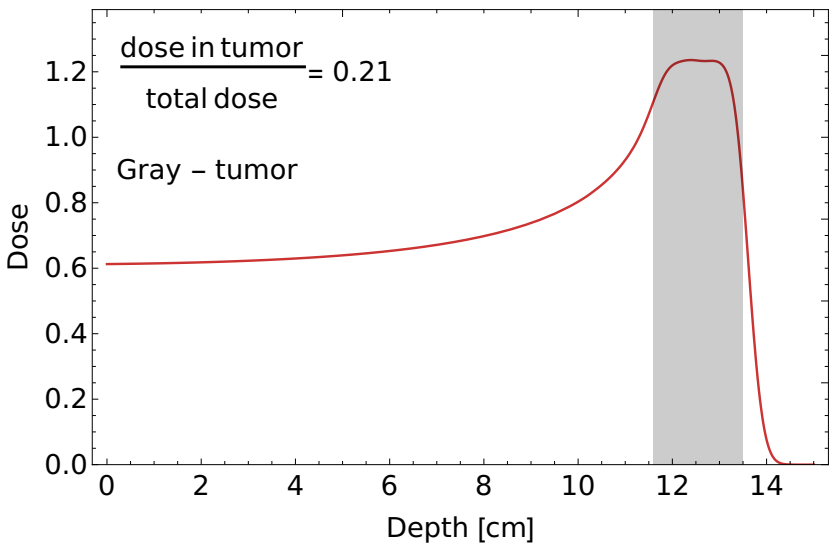
Units of electric potential (y direction out of the plane) are V/C.

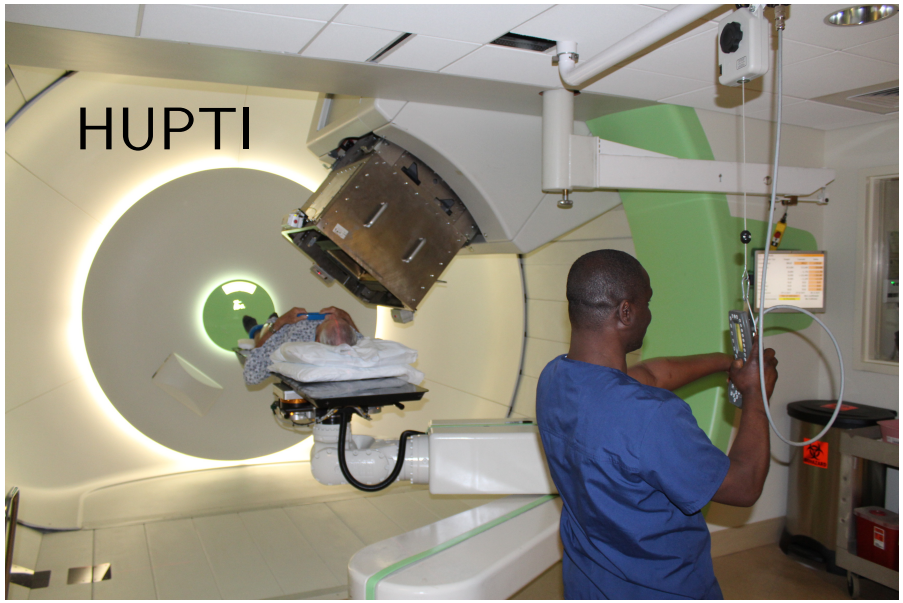
Use of Power Supply

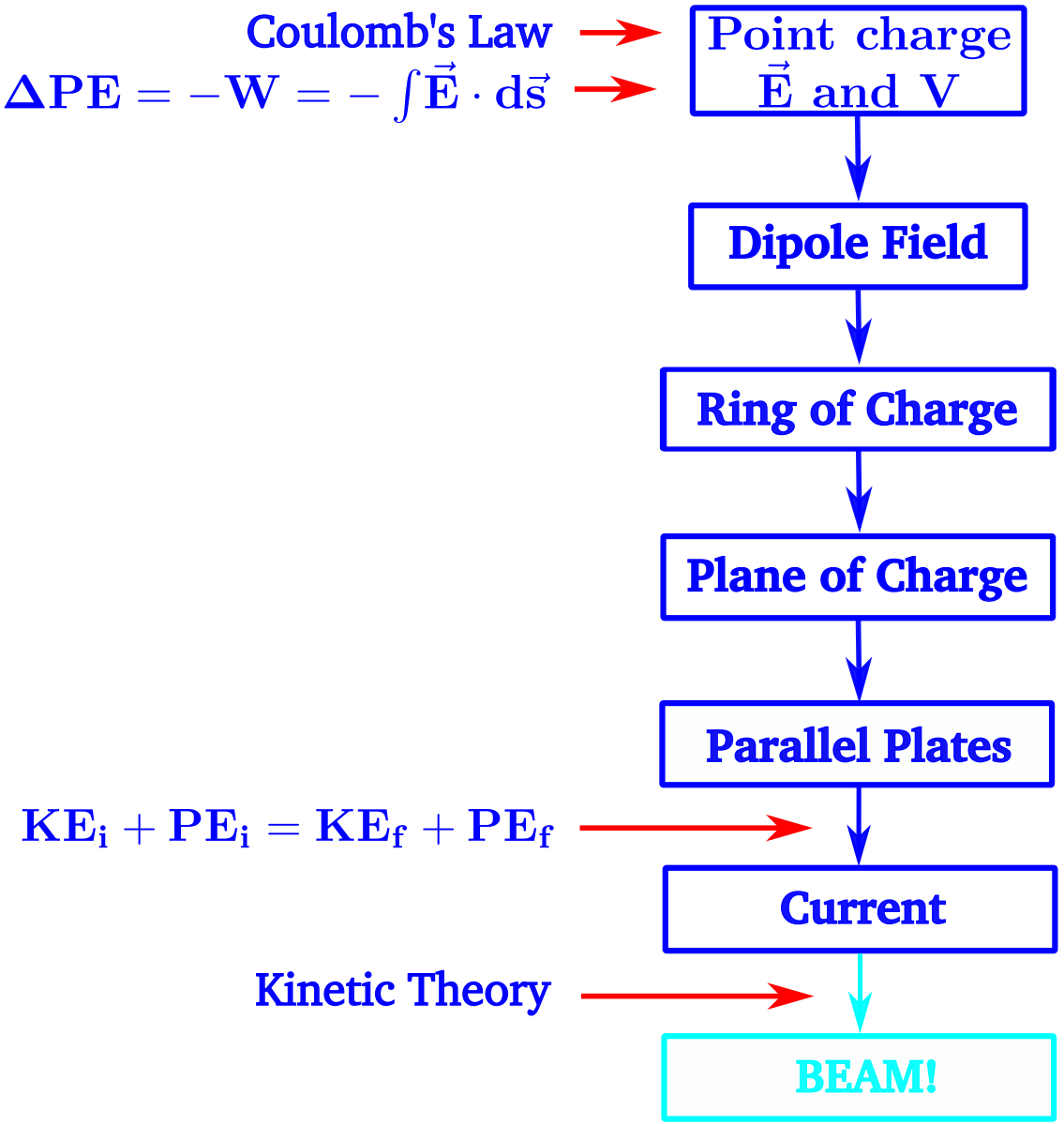
1. Before plugging it in make sure it is off. The power switch should be out and the voltage knobs, coarse and fine, turned all the way down (counterclockwise).
2. Plug in the supply.
3. Hook up your circuit.
4. Set the meter switch on the readout to volts.
5. With the voltage knob still turned down, toggle the power switch. The readout should be zero.
6. You can now turn up the voltage as required. You may have to adjust the current limiting knob.

New Treatments for Cancer 41

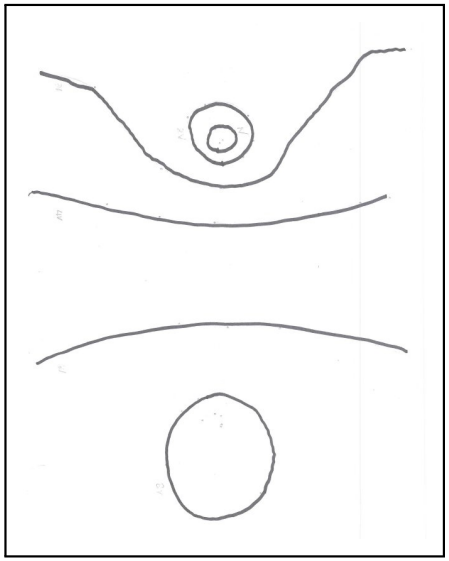
In proton-beam therapy, high-energy protons are used to kill tumors. In one case an energy $E_{dep} = 200\ J$ must be deposited into the tumor. However, only 21% of the incident proton energy E_{inc} actually goes into the tumor. To create the beam, protons are accelerated from rest through an electric potential difference $V_p = 100\ MV = 10^8\ V$. The total exposure time is to be three minutes. What is the electric current during the treatment? If the beam spot is circular with radius $r = 0.1\ m$, what is the beam proton density? Compare this with the proton density of water ($\approx 10^{28}\ m^{-3}$).



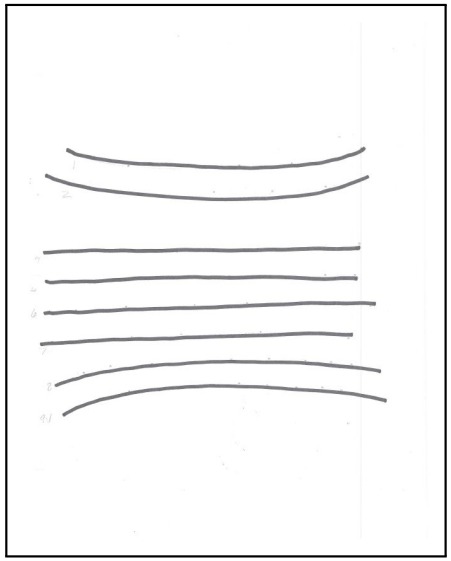



Coulomb's Law
$\Delta PE = -W = -\int \vec{E} \cdot d\vec{s}$
Point charge
$\vec{E}$ and V
Dipole Field
Ring of Charge
Plane of Charge
Parallel Plates
$KE_i + PE_i = KE_f + PE_f$
Current
Kinetic Theory
BEAM!

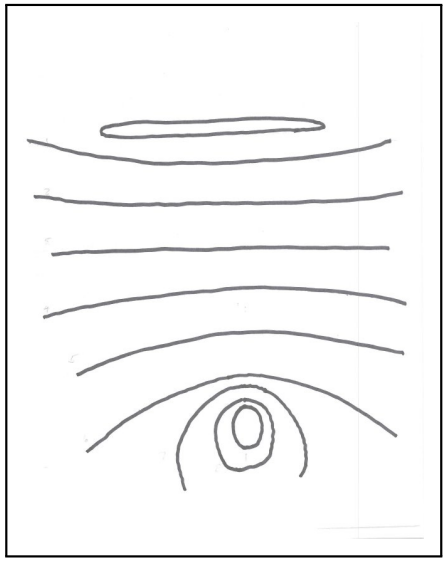
Measuring Equipotential Lines and Electric Fields 43



two point charges

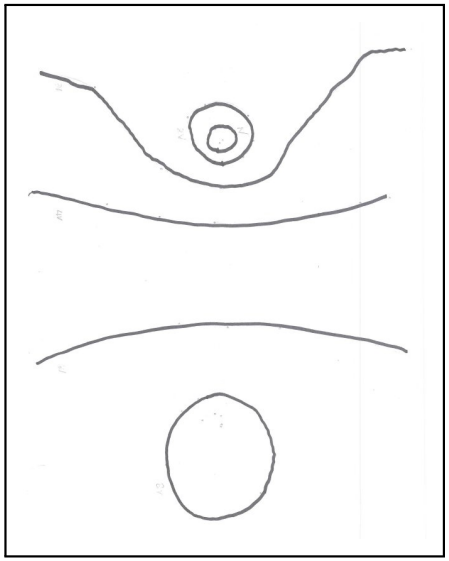


two line charges

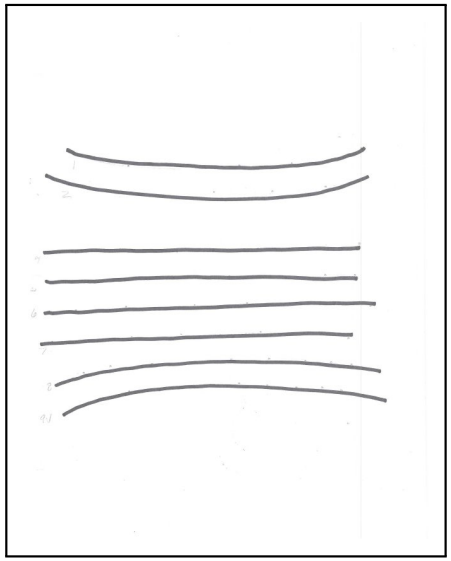


line and point charge

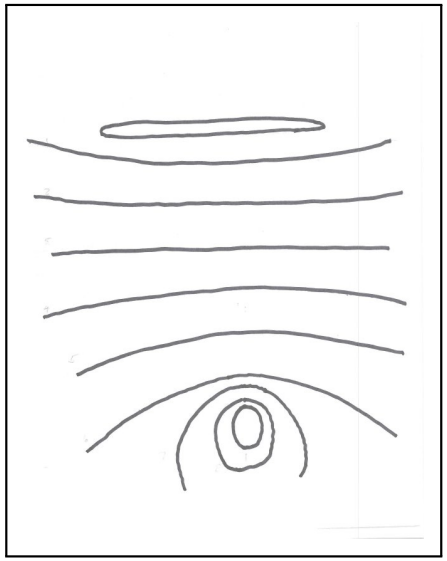
Measuring Equipotential Lines and Electric Fields 44



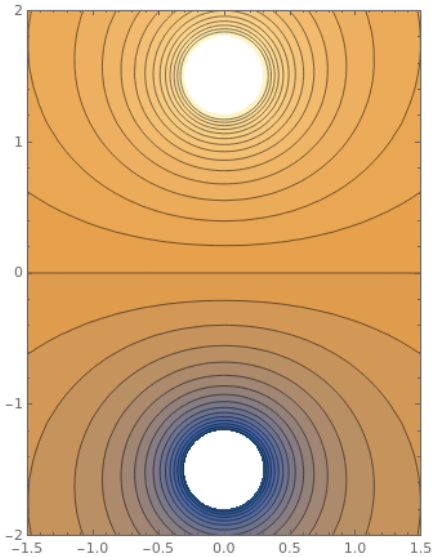
two point charges

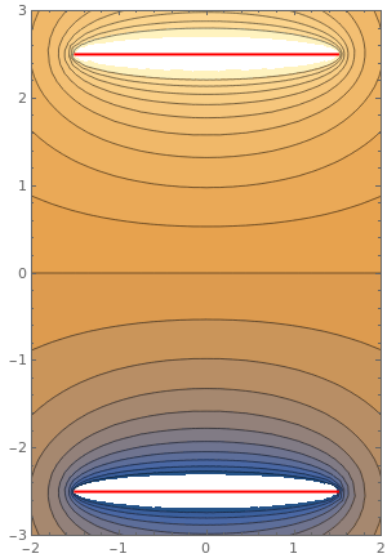


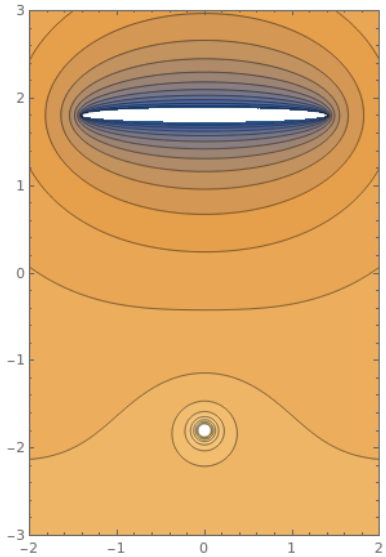
two line charges



line and point charge







New Treatments for Cancer 45

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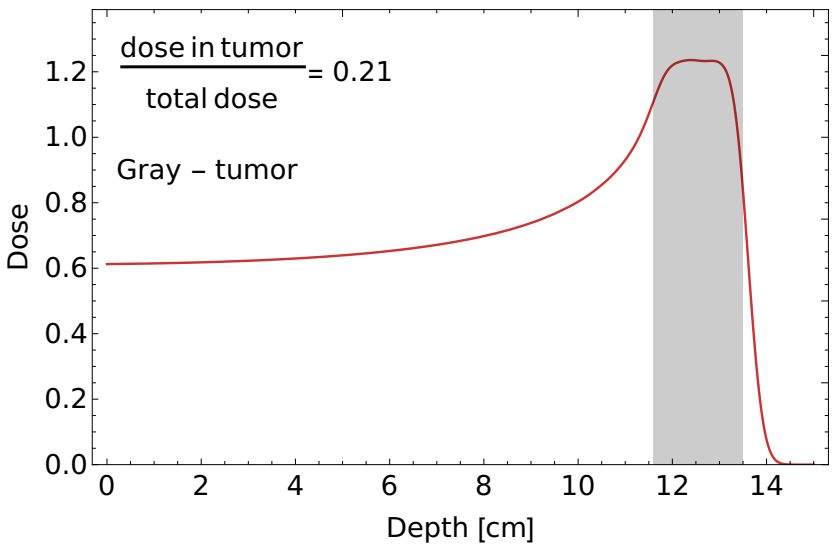
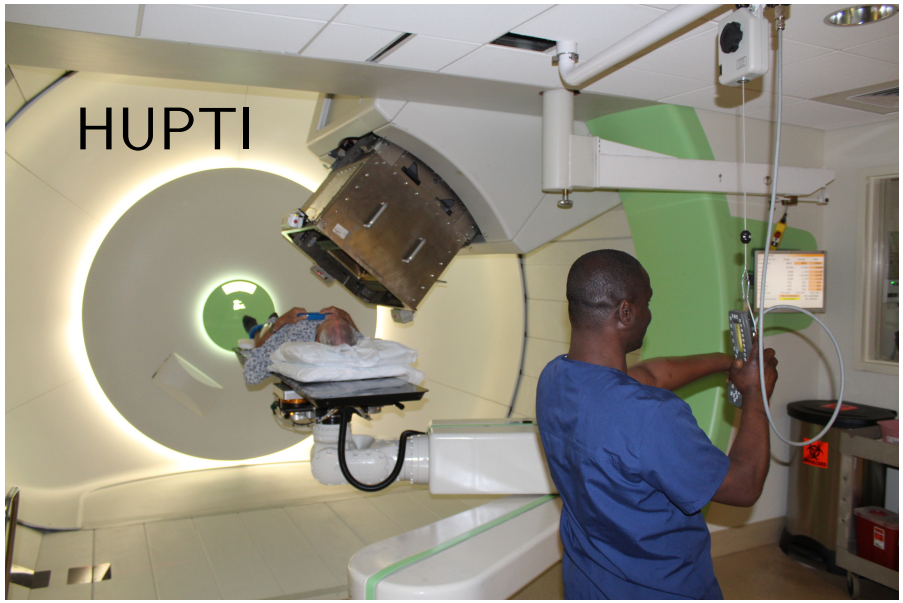
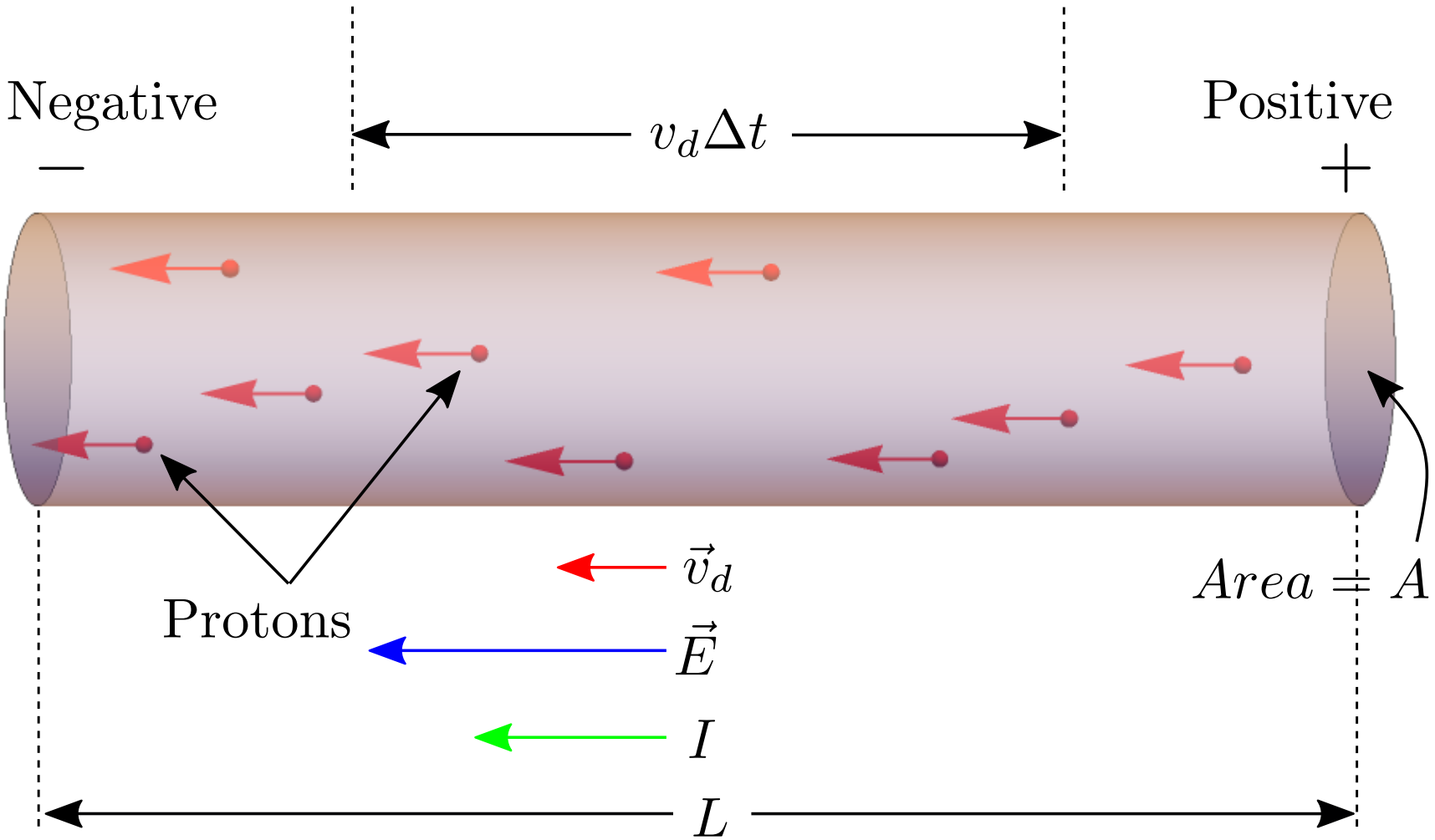
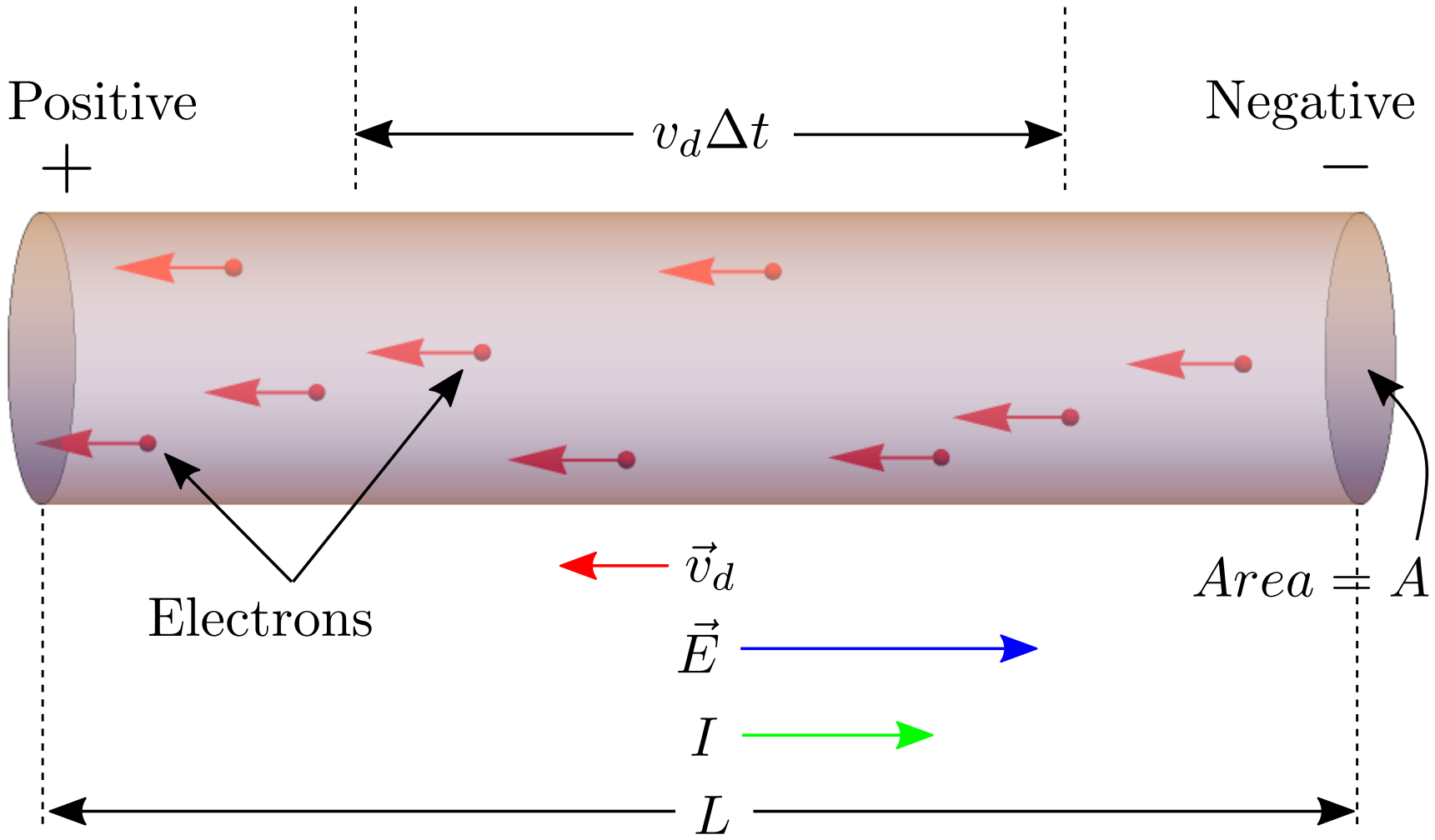


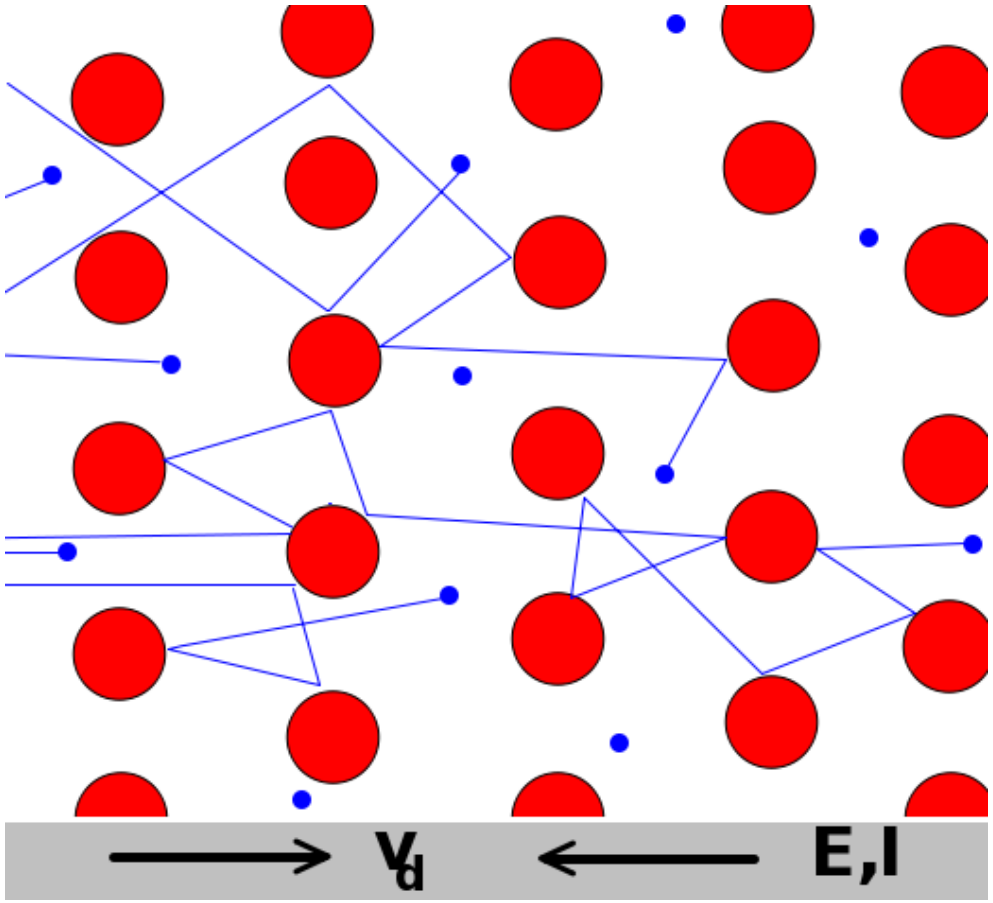



Negative
−
$v_d\Delta t$
Positive
+
Protons
$\vec{v}_d$
$\vec{E}$
I
L
$Area = A$


Positive
+
$v_d\Delta t$
Negative
−
Electrons
$\vec{v}_d$
$\vec{E}$
I
L
$Area = A$

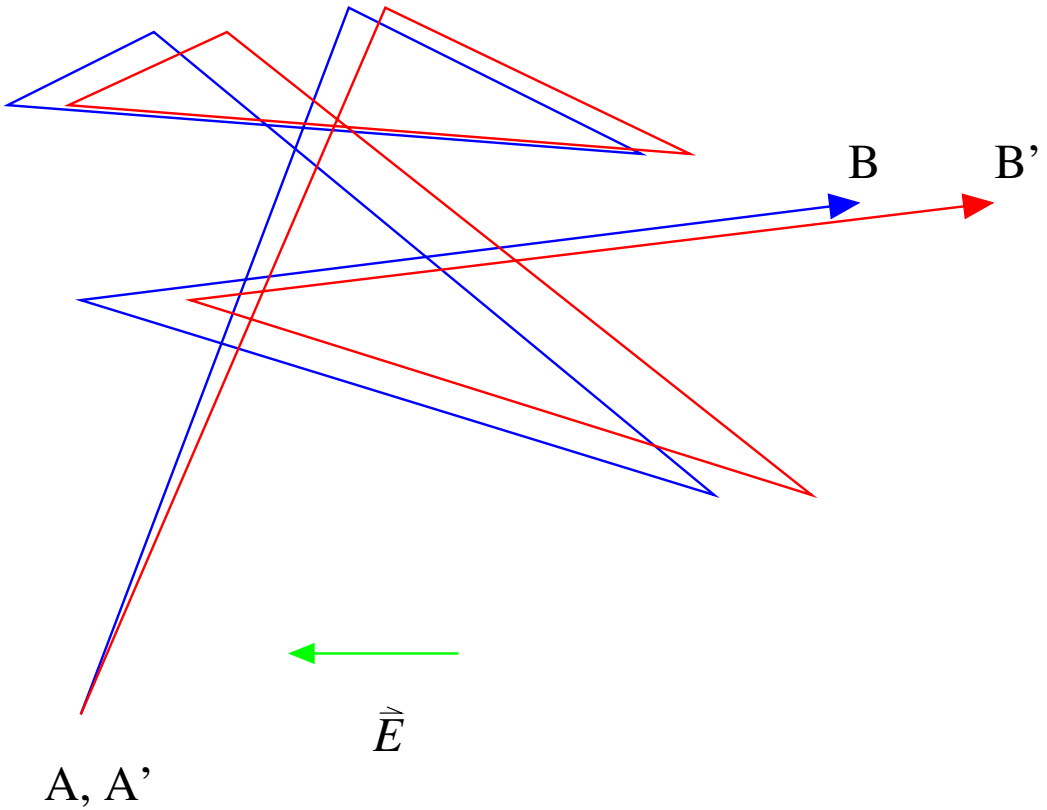
The Drift Velocity of Conduction Electrons - 2 48

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.



A copper wire carrying a current $i = 20\ C/s$ 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 $T = 25^{\circ}C$?

Electron Paths in a Metal



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

New Treatments for Cancer 51

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