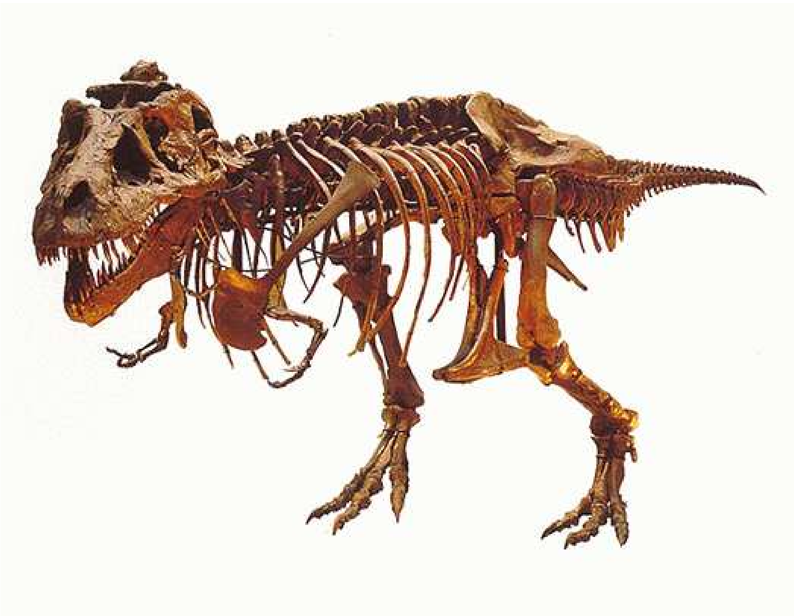
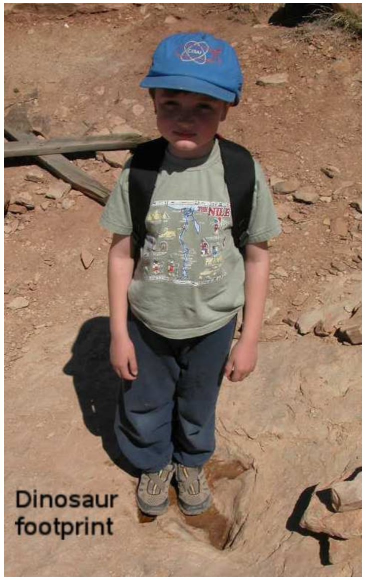
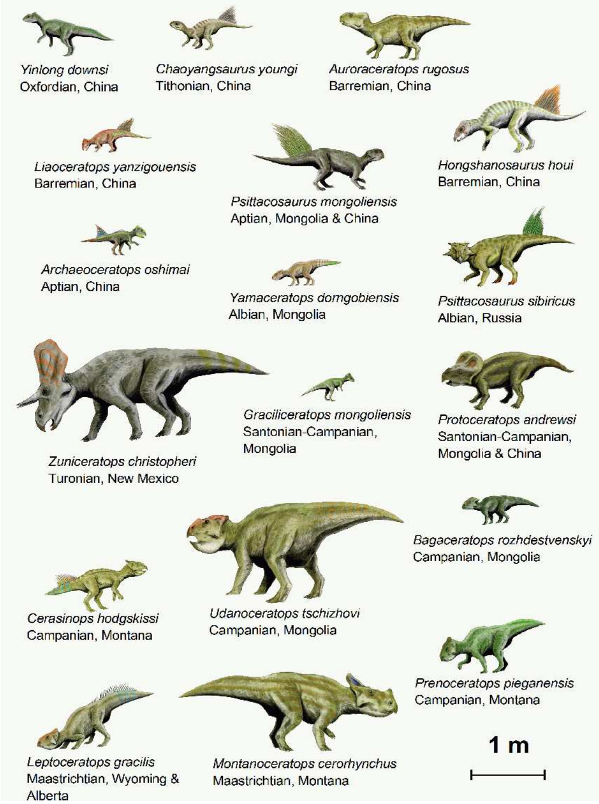
What Happened to the Dinosaurs?

Dinosaurs were the dominant vertebrate animals of terrestrial ecosystems for over 160 million years from about 230 million years ago to 65 million years ago. Recent research indicates that theropod dinosaurs are most likely the ancestors of birds and many were active animals with elevated metabolisms often with adaptations for social interactions. What caused them to largely disappear?

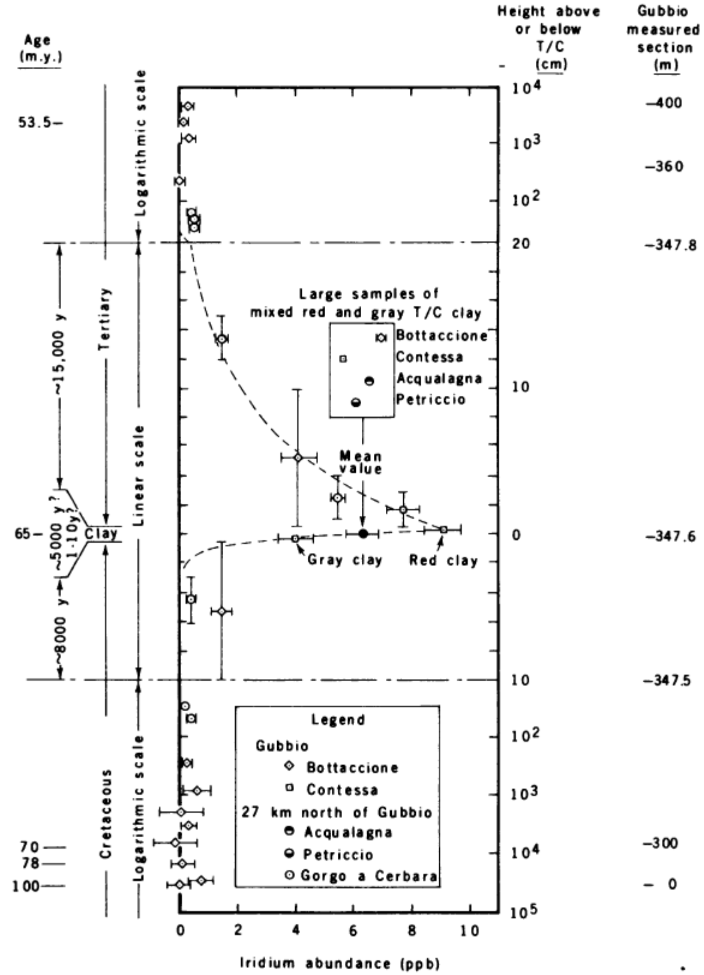






Evidence of an Asteroid Strike

1. The dinosaurs disappeared at the boundary between the Cretaceous and Tertiary Periods (the KT Boundary) about 65 million years ago.
2. The data in the figure shows the abundance of the atom iridium which is commonly found in meteorites and not on Earth. The horizontal axis is the iridium abundance and the vertical axis is the age of the sample with increasing age going down.
3. The large peak in the iridium abundance implies a large infusion of the atom coincident with the KT boundary. This peak was observed in rocks from Italy, Denmark, and New Zealand.

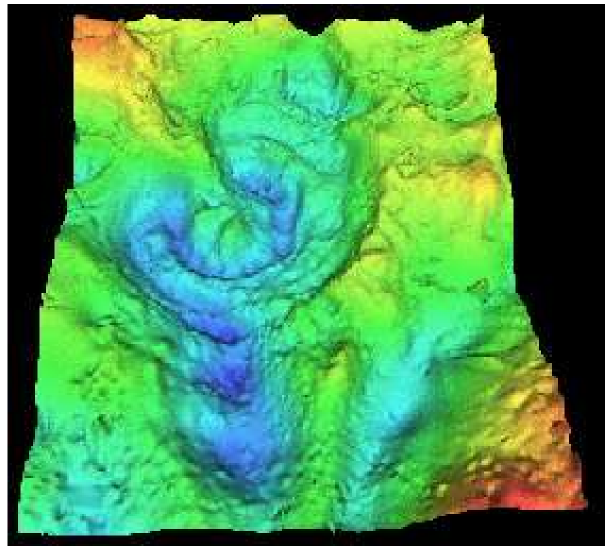


L.W.Alvarez, W.Alvarez, F.Asaro, H.V.Michel, *Science*, “Extraterrestrial Cause for the Cretaceous-Tertiary Extinction”, 208 (1980) 1095.

More Evidence (and What to Worry About)

1. An impact crater of the right size and age has been found on the Yucatan Peninsula in Mexico showing signs of shocked crystals and melted rock.
2. There is abundant evidence of other cataclysmic collisions with Solar System debris.
3. Frequency of impacts:

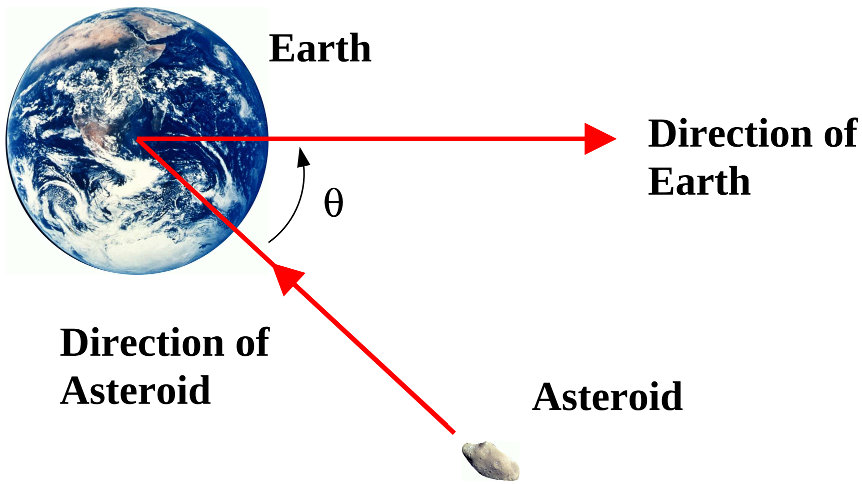
Pea-size meteoroids	10 per hour
Walnut-size	1 per hour
Grapefruit-size	1 every 10 hours
Basketball-size	1 per month
50-m rock	1 per 100 years
1-km asteroid	1 per 100,000 years
2-km asteroid	1 per 500,000 years



The End of the Dinosaurs

It is now believed the dinosaurs and many other species were driven to extinction 65 million years ago by an ecological disaster brought on by the collision of an asteroid with the Earth. Consider the following scenario. The asteroid collides with the Earth as the Earth orbits the Sun and sticks to the surface as shown in the figure (a perfectly inelastic collision). How much does the velocity of the Earth change? How much energy is released in the collision? How does this compare with the energy released by the Hiroshima atomic bomb ($6.8 \times 10^{13}\ J$)?

Asteroid mass:	$m_A = 3.4 \times 10^{14}\ kg$
Asteroid speed:	$v_A = 2.5 \times 10^{5}\ m/s$
Earth mass:	$m_E = 6.0 \times 10^{24}\ kg$
Earth speed:	$v_A = 3.0 \times 10^{4}\ m/s$
Angle:	$\theta = 30°$

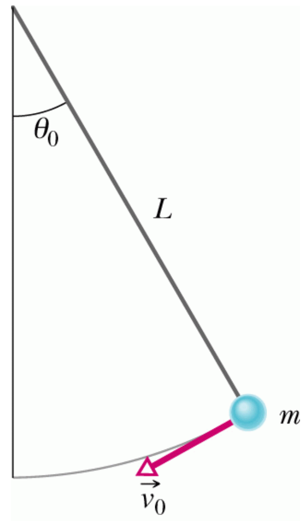


Some Work Examples

1. An elevator is carrying a load of people between two floors. The mass of the elevator and the passengers is $m = 500\ kg$. Calculate the work done as the elevator moves upward a distance $y = 3\ m$ between the two floors at constant speed. What is the work done when the elevator moves down?
2. A cart is pulled across a flat surface with a rope at an angle $\theta = 60^\circ$ to the horizontal for a distance $x = 3\ m$. The magnitude of the force is $|\vec{F}| = 3\ N$ and the mass of the cart is $m = 5\ kg$. Assume the cart rolls with no effect due to friction. What is the work done by the force?

Kinetic and Potential Energy Examples - 1

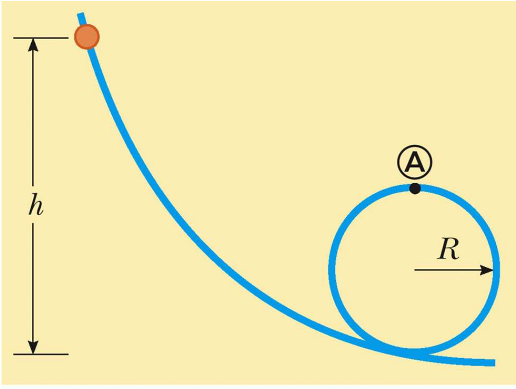
1. The figure shows a thin rod of length L and negligible mass that can pivot about one end and rotate in a vertical circle. The rod is pulled to one side to an initial angle θ and released. What is the speed of the ball at its lowest point if $L = 2.0\ m$ and $\theta = 30°$?



2. A projectile of mass $m = 0.050\ kg$ is thrown from a window with an initial velocity $v_0 = 8\ m/s$ at an angle $\theta = 30°$ above the horizontal. What is the kinetic energy of the ball at the top of its flight? What is the speed when it is a distance $3.0\ m$ below the release point?

Kinetic and Potential Energy Examples - 2

1. A roller coaster car rolls without friction around a loop as shown in the figure. The car starts from a height $h = 3.5R$ where R is the radius of the loop. What is its speed at point A? How large is the normal on it there if its mass is $m = 150\ kg$ and $R = 5\ m$?

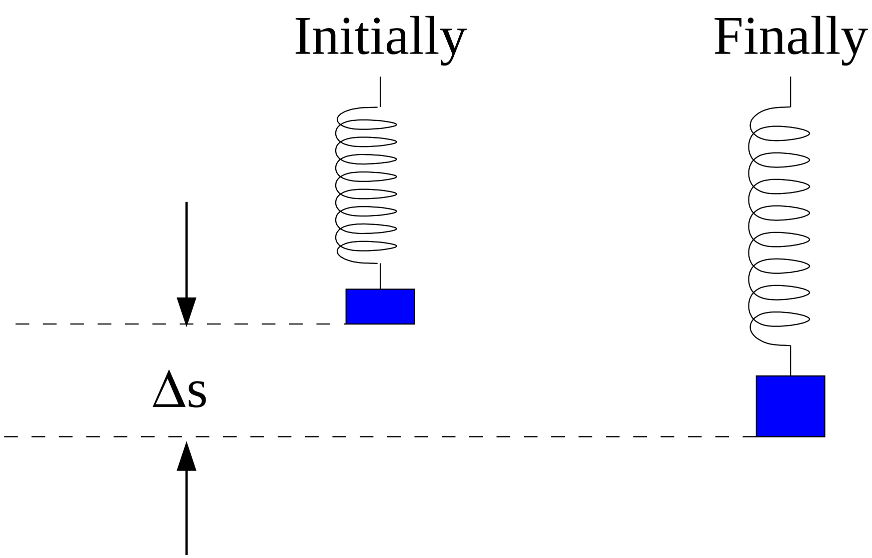


Variable Forces

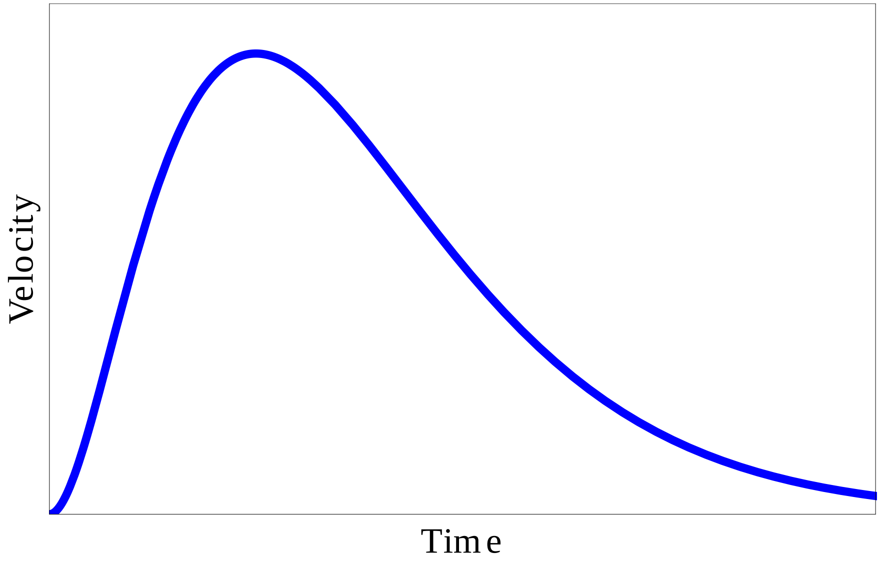
A spring, when stretched, exerts a restoring force that pulls the spring back to its equilibrium position.

$$\vec{F}_s = -k\vec{s}$$

The vector $\vec{s}$ is the displacement of the end of the spring from its equilibrium position. A one-dimensional force $F_1 = 5\ N$ is applied to a spring stretching it from its relaxed, equilibrium state a distance of $|\vec{s}_1| = s_1 = 0.12\ m$. Then, an additional force $F_2 = 2\ N$ is added and the spring stretches another $\Delta s = 0.05\ m$. What is the work done by the spring for each part? The spring constant is $k = 42\ N/m$.



Integrating the Velocity



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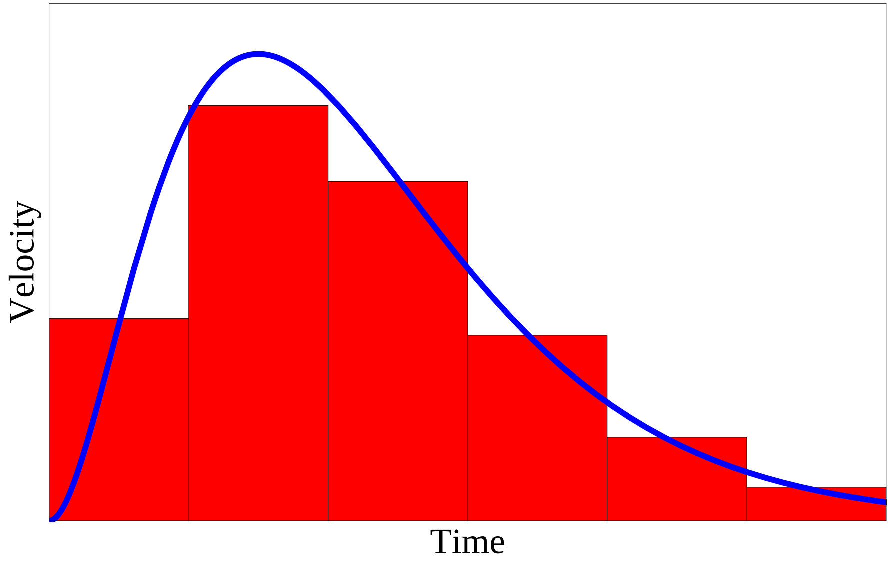

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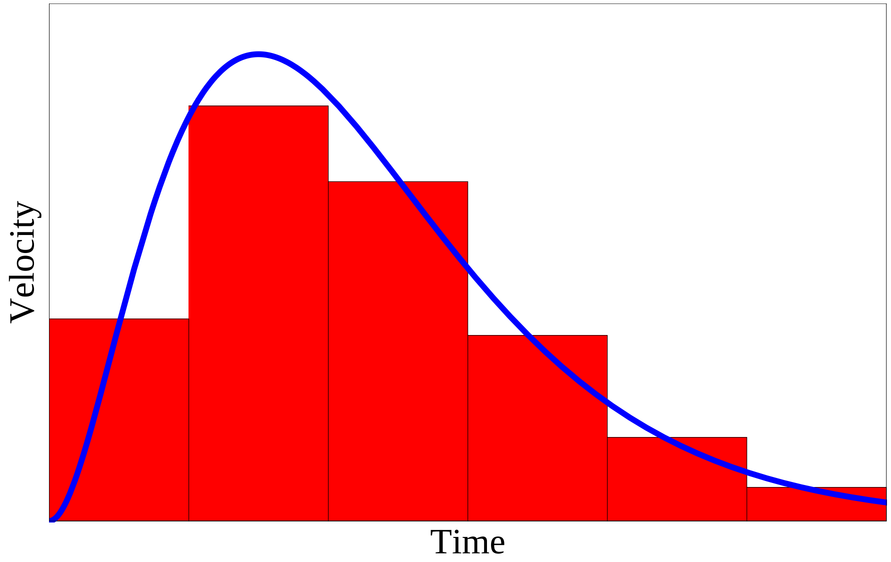
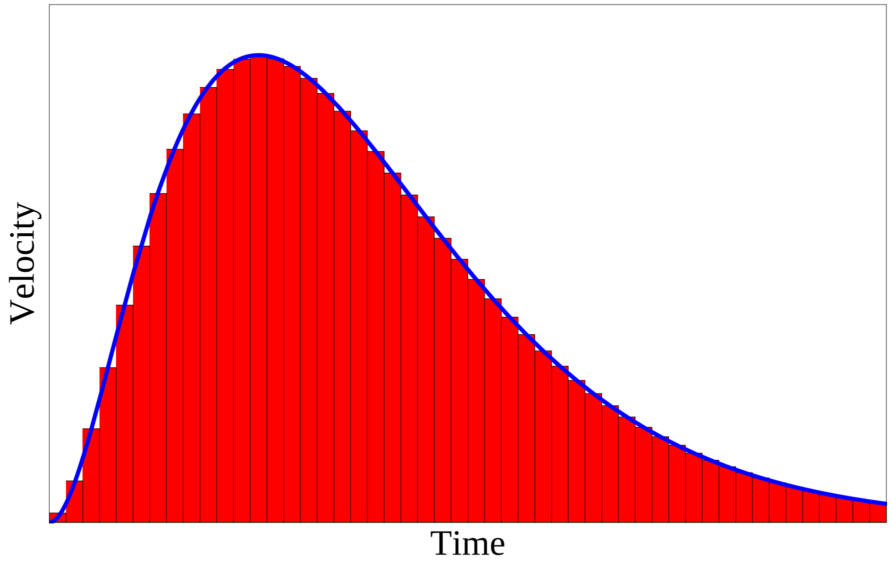
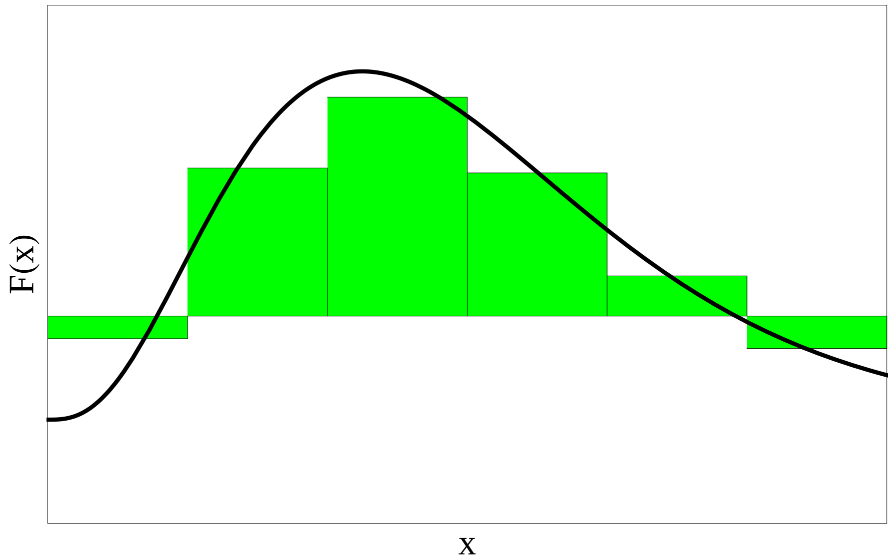




Work and Variable Forces



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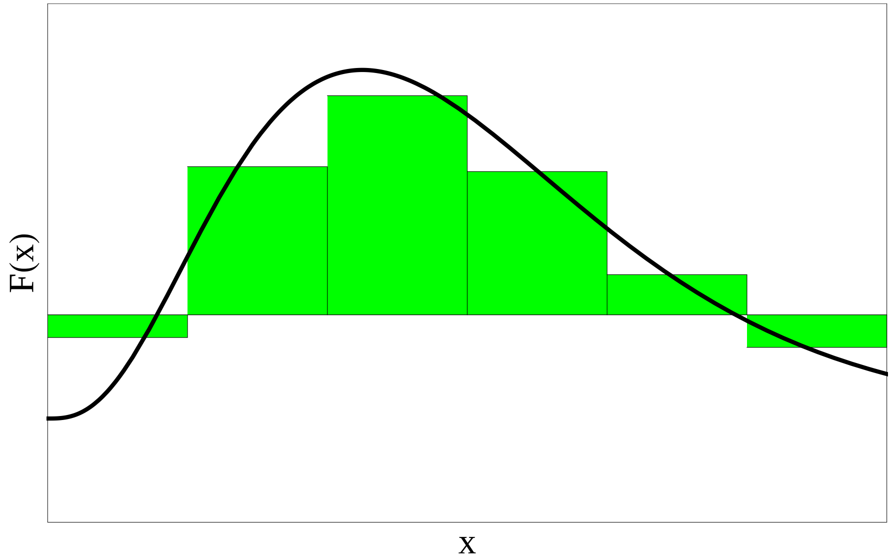

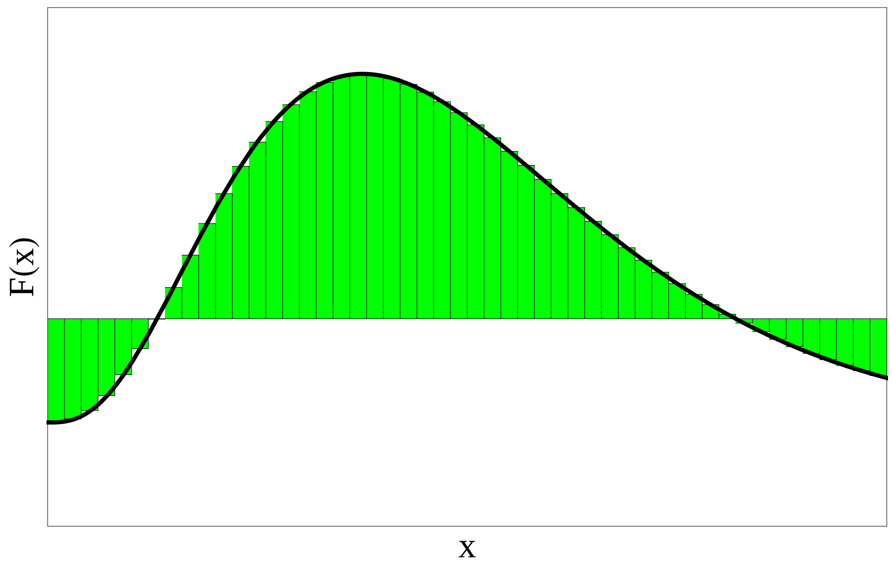

More on Variable Forces

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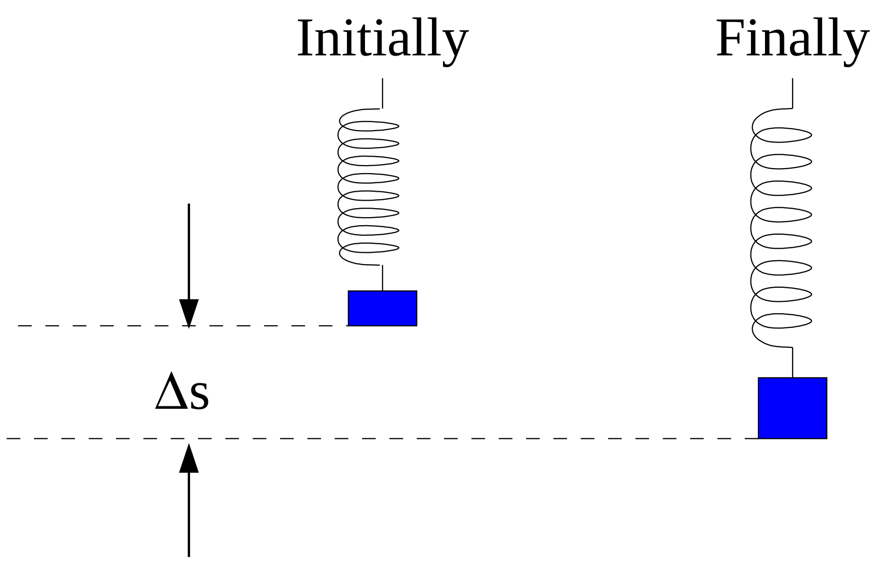


Quarks on Springs

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

Leptons spin = 1/2

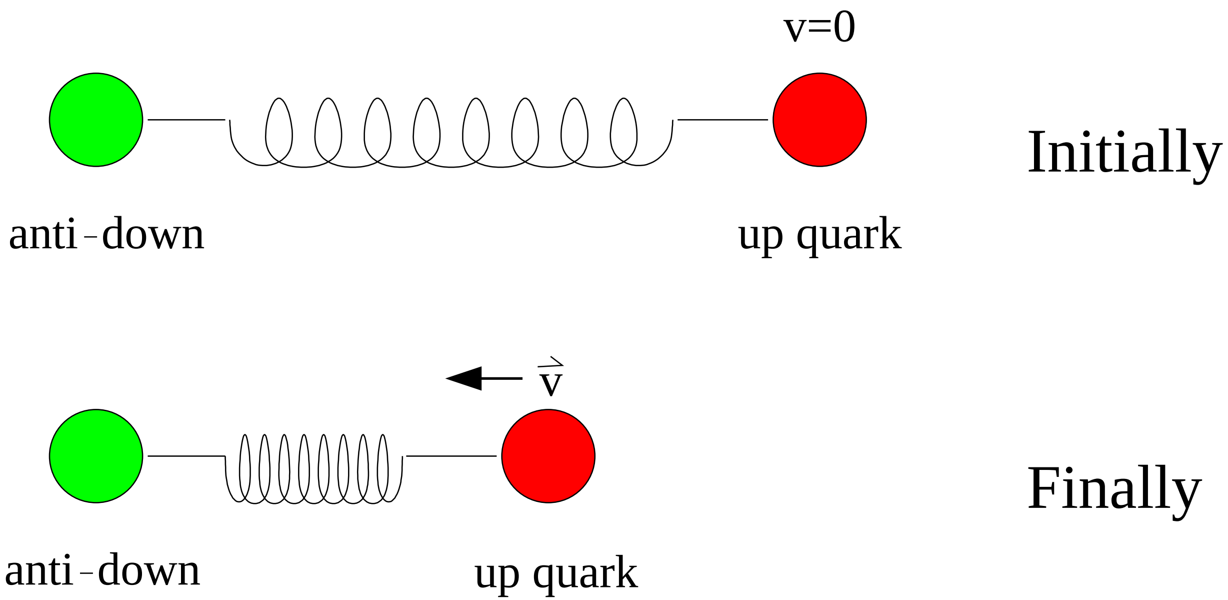
Flavor		Mass GeV/c^2	Electric charge
ν_e	electron neutrino	$<1\times10^{-8}$	0
e	electron	0.000511	−1
ν_μ	muon neutrino	<0.0002	0
μ	muon	0.106	−1
ν_τ	tau neutrino	<0.02	0
τ	tau	1.7771	−1

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

Quarks on Springs

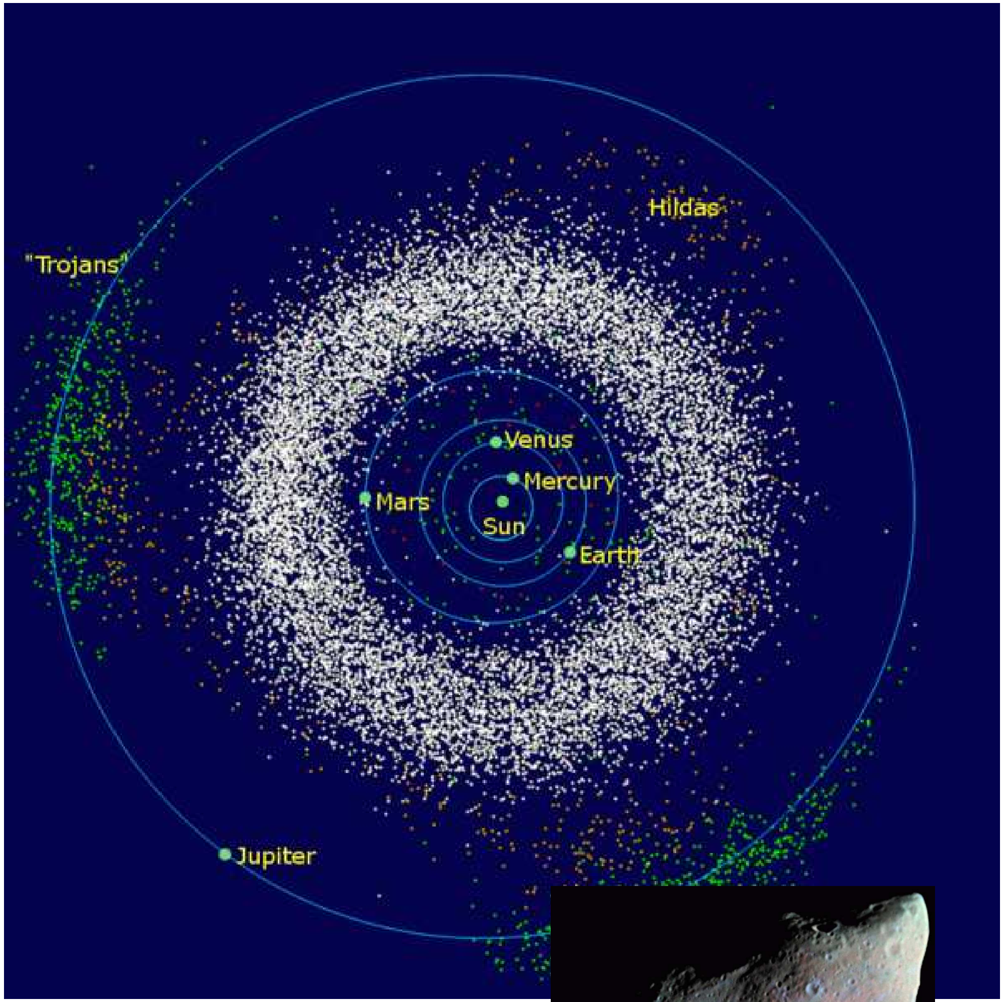
Two quarks, an up and an anti-down are bound together (much like atoms bind together to make molecules) to form an object known as a pi meson or pion (π^+). The force between the quarks can be modeled as a spring force to explain their confinement in the pion. If the spring with the up quark attached is stretched a distance $s = 1.2 \times 10^{-15}\ m$ from equilibrium and released from rest, then what is the kinetic energy and speed of the up quark when the spring passes through its equilibrium point and becomes relaxed? Treat the position of the anti-down quark as fixed. The spring constant is $k = 6.0 \times 10^{17}\ N/m$ and the mass of each quark is $m_q = 1.4 \times 10^{-28}\ kg$.



The Birthplace of Asteroids

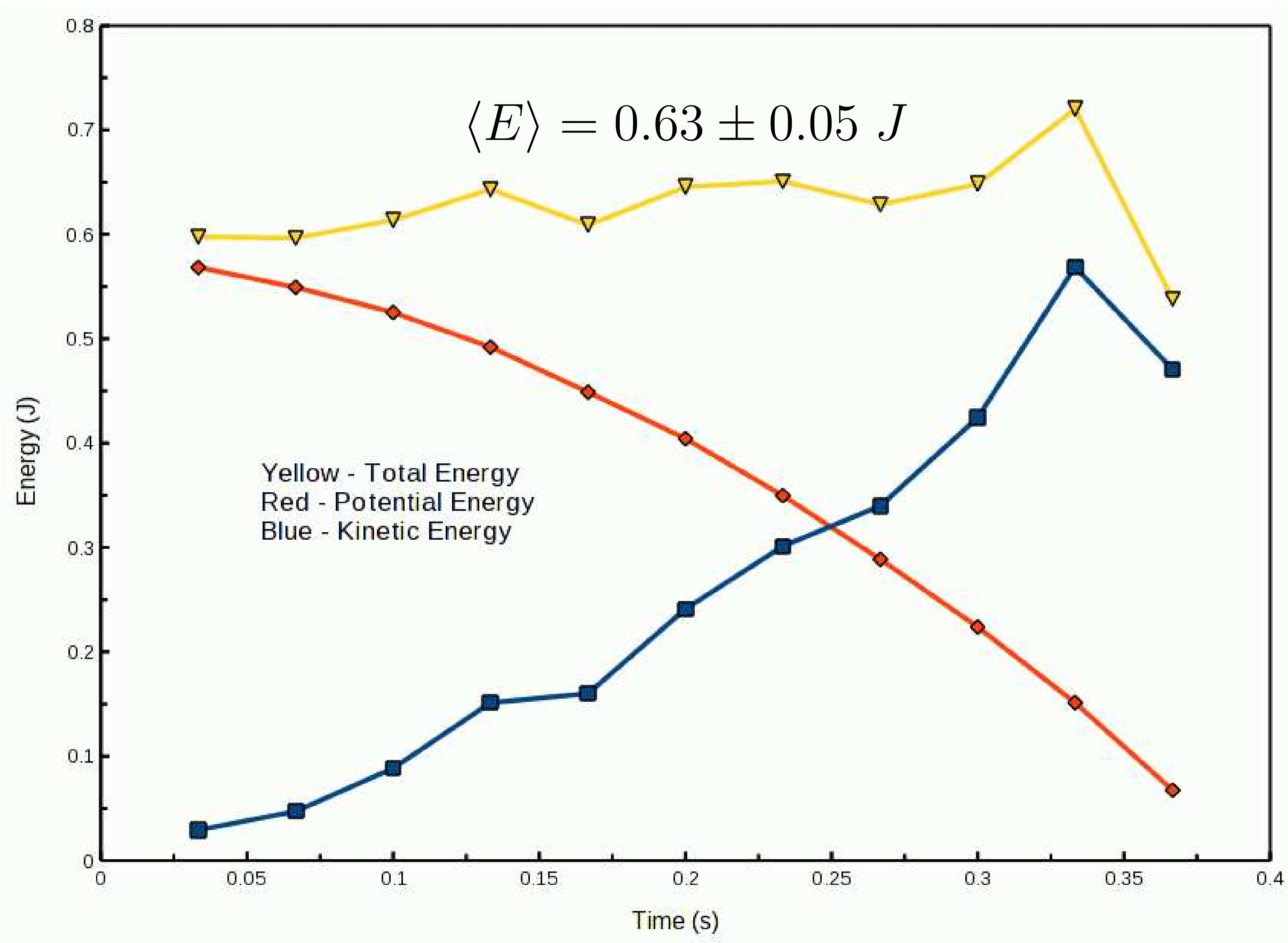
The asteroid belt is a region of our Solar System occupied by many large rocks and is located between the orbits of Mars and Jupiter. Its center is about $r_A = 4.0 \times 10^{11}\ m$ from the Sun. Suppose an asteroid from this region fell down to the orbit of Earth ($r_E = 1.5 \times 10^{11}\ M$). What is the minimum potential energy it would lose? What will be its minimum speed? Some useful numbers are below. The asteroid mass is the same as the value used by Alvarez *et al.* in their hypothesis for the dinosaur killer.

Solar mass	$1.99 \times 10^{30}\ kg$
Earth mass	$5.98 \times 10^{24}\ kg$
Asteroid mass	$3.4 \times 10^{14}\ kg$



First image of an asteroid from a spacecraft (Galileo, 1991).

'Proof' of Mechanical Energy Conservation

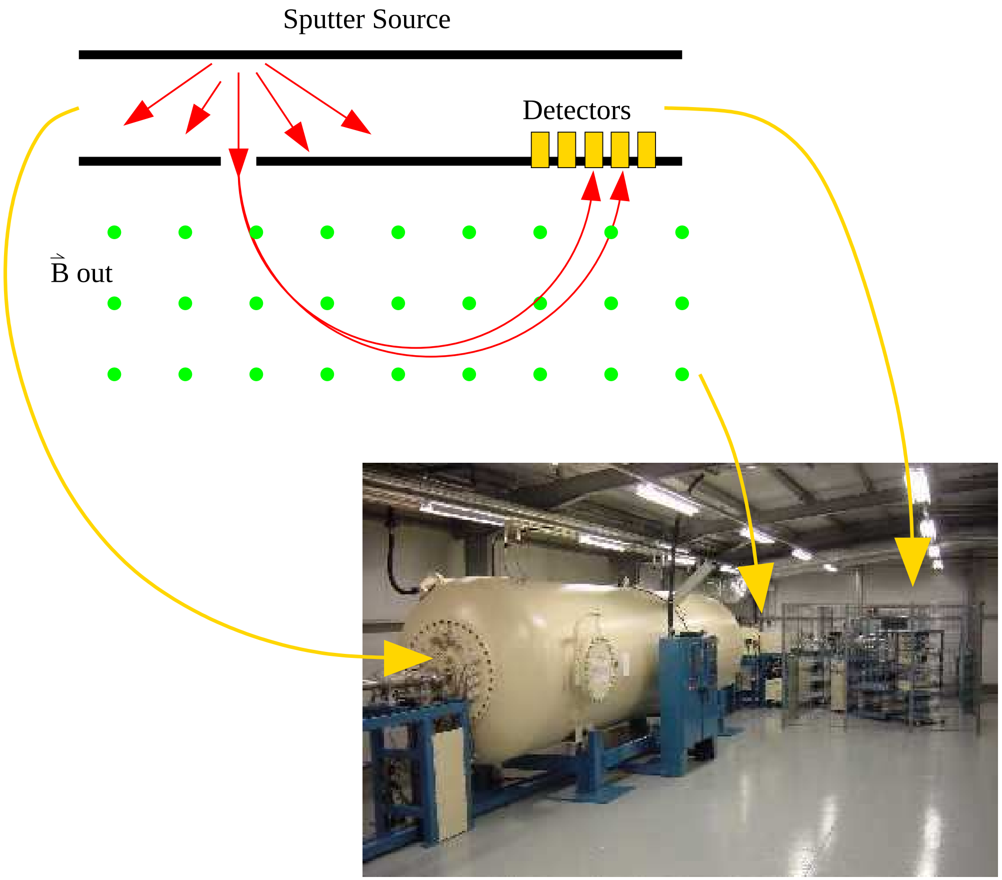


Mass Spectrometry

Mass spectrometry is a technique for identifying and characterizing sub-atomic, atomic, and molecular particles using the ratio of electric charge to mass. Some applications are listed below and here.

1. Particle identification.
2. Radiocarbon dating.
3. Chemical analysis.
4. Respired gas monitor.
5. Space exploration.
6. Art fraud analysis.
7. Pharmacokinetics.
8. Protein characterization.
9. Nuclear nonproliferation.
10. ...

A Mass Spectrometer



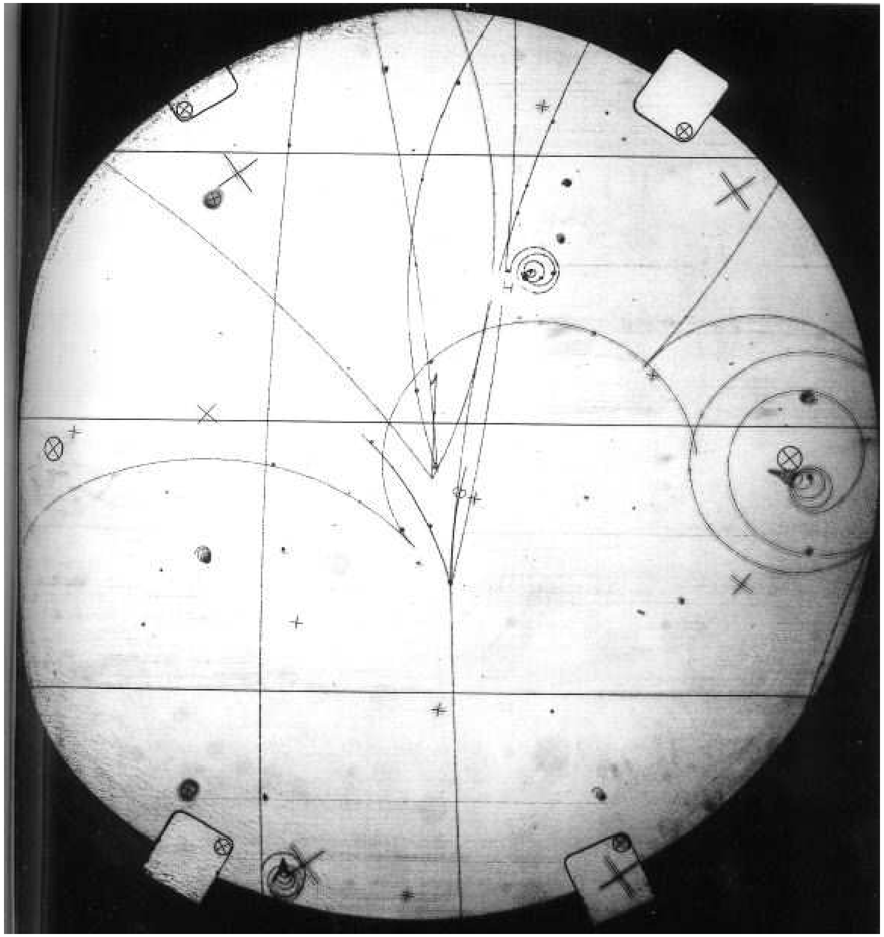
Recoil!

A cannon of mass $m_c = 1300\ kg$ fires a shell of mass $m_s = 72\ kg$ with a muzzle velocity $v_s = 55\ m/s$. The cannon is mounted so it can recoil freely. What is the recoil speed?

Subatomic Decays

A subatomic particle known as a Λ_0 decays from rest by emitting a proton of kinetic energy $E_1 = 10$ MeV and a second unknown particle of kinetic energy $E_2 = 67$ MeV. Identify the unknown particle x using the table of particle masses below.

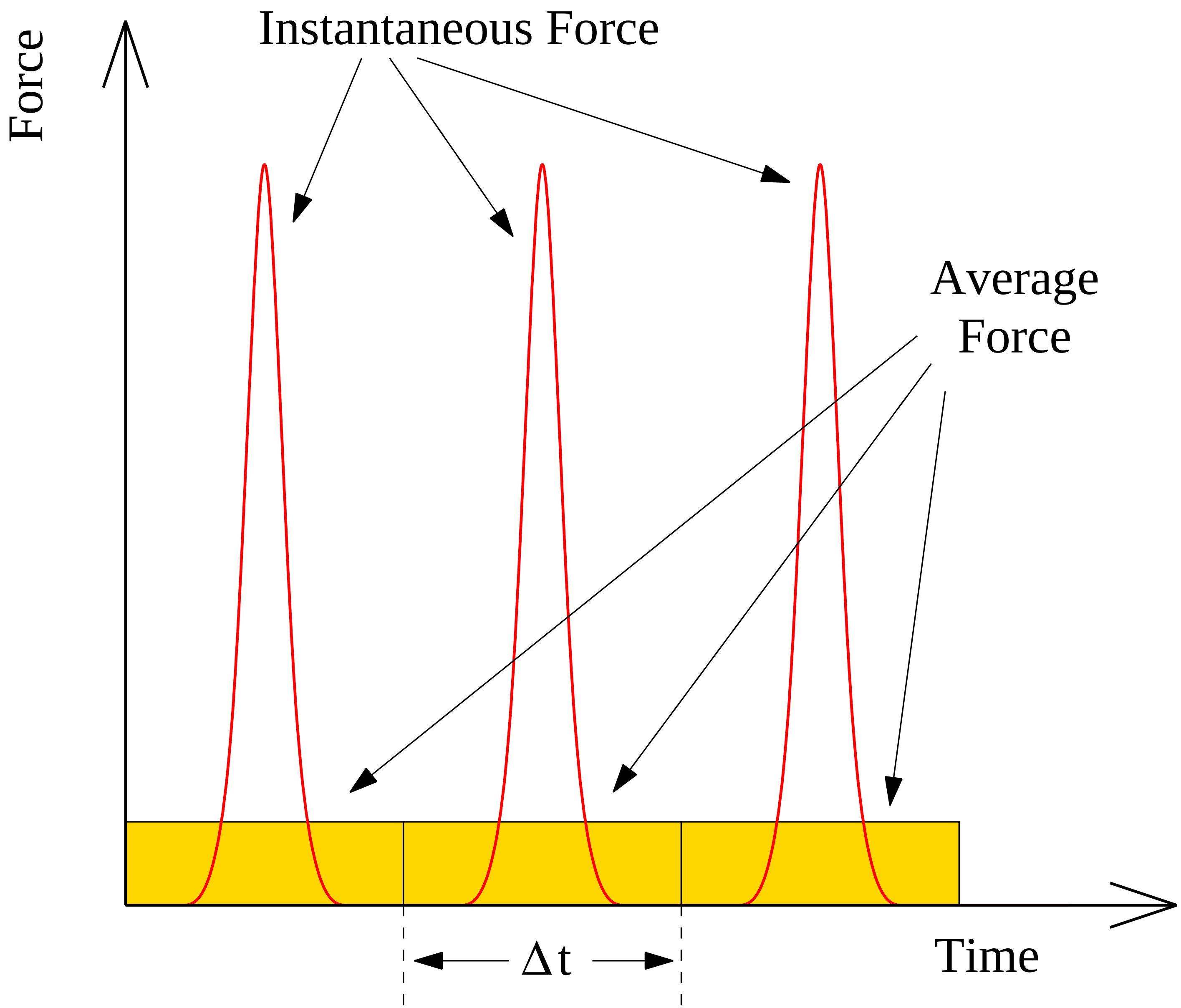
Particle	Mass (MeV/c^2)
Electron (e)	0.551
Muon ($\mu^{\pm}$)	106
Pion ($\pi^{\pm}$)	139
Kaon ($K^{\pm}$)	494
Eta (η)	549
Proton (p)	938
Neutron (n)	939
Lambda (Λ_0)	1116



Superman To the Rescue!

It is well known that bullets fired at Superman simply bounce off his chest. Suppose a Mafia hit man sprays Superman's chest with bullets of mass $m_b = 25.0\ g$ at a rate $R = 100\ bullets/min$. The speed of each bullet is $v_b = 1500\ m/s$. These are roughly the parameters of a 44-Magnum pistol. Suppose further the bullets bounce straight back with no loss in speed. Find the impulse delivered by each bullet and the average force exerted on Superman.

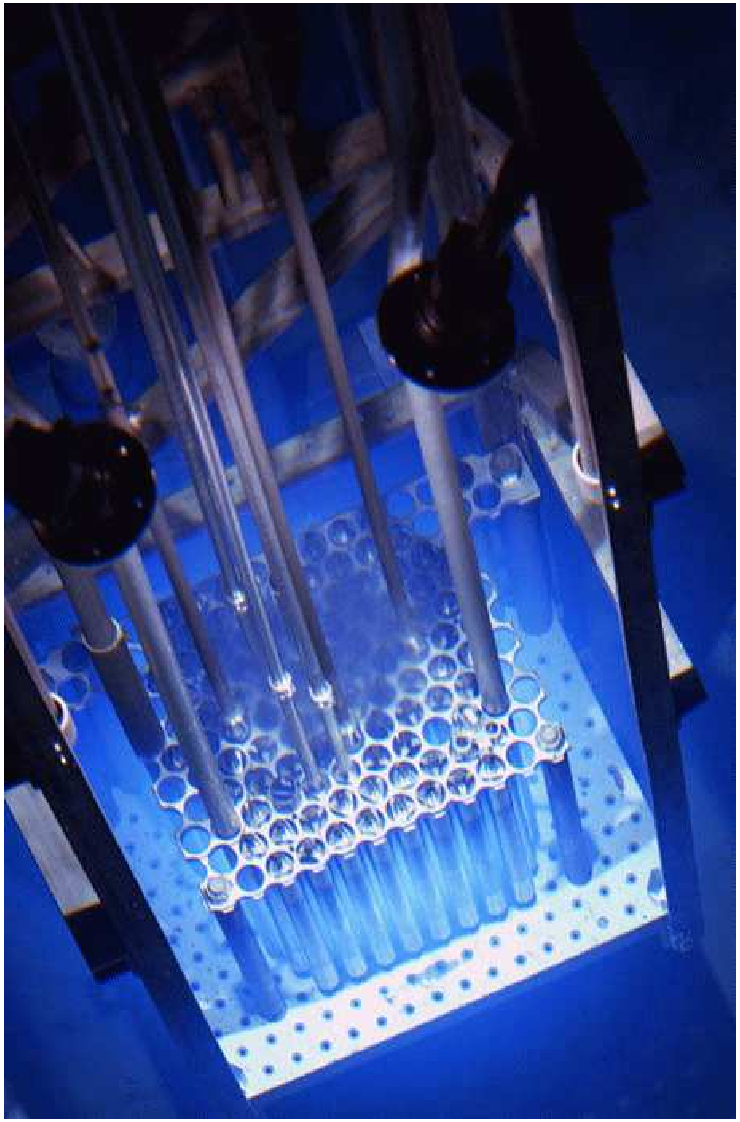
Instantaneous versus Average Force



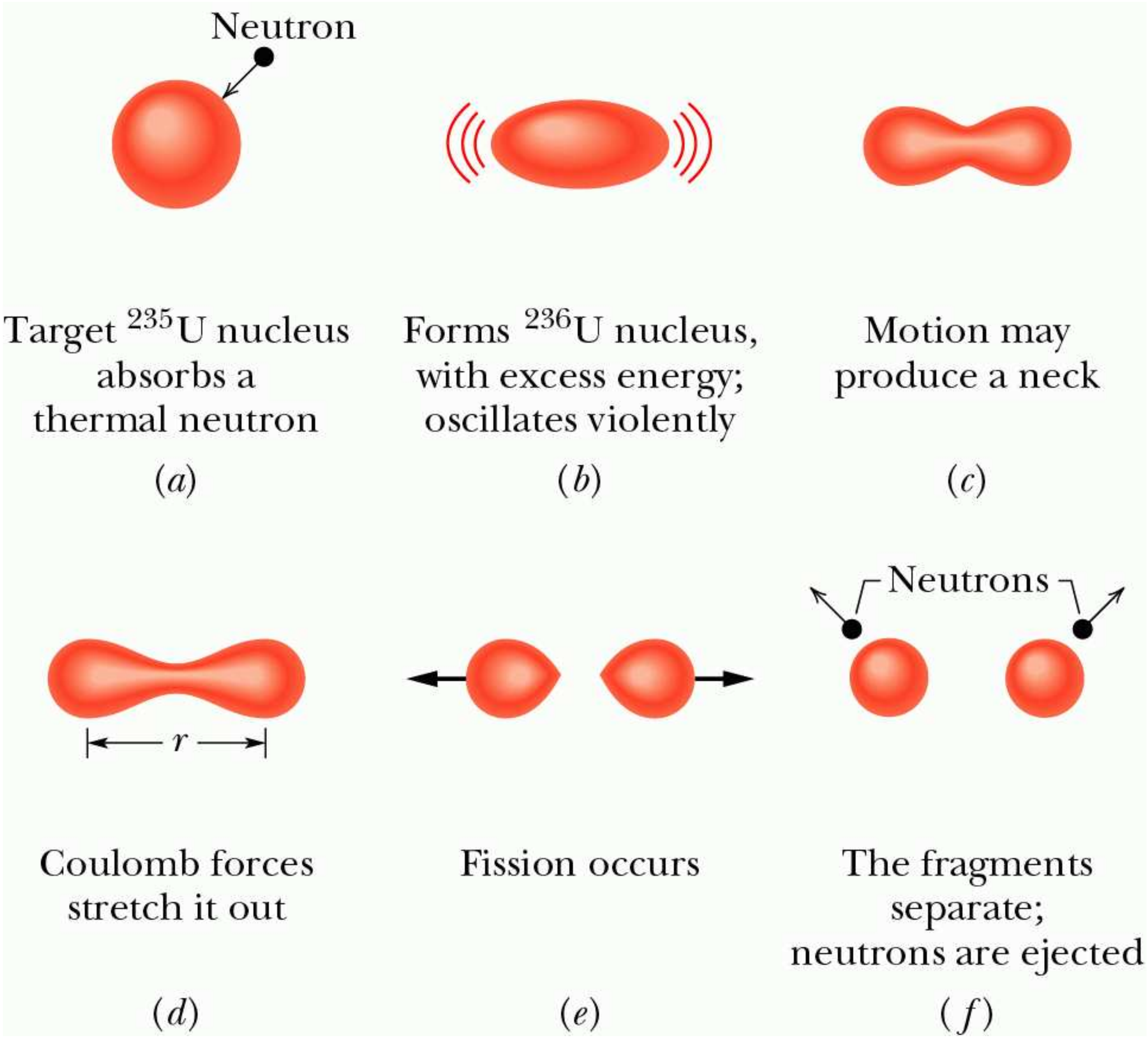
Nuclear Collisions

In a nuclear reactor heavy atomic nuclei like uranium are irradiated with neutrons which cause them to split apart ('to fission'); releasing energy that can be used to make electricity. A byproduct of the fission event is additional neutrons that can cause further fissions and energy release. However, these neutrons usually have too much kinetic energy to cause fissions so they have to be slowed down ('moderated') by making them collide with some surrounding material.

One of these too-fast neutrons ($m_n = 1\ u$) makes an elastic, head-on collision with the nucleus of a carbon atom ($m_c = 12\ u$) at rest. The initial kinetic energy of the neutron is $E_0 = 1\ \mathrm{MeV}$. What fraction of the neutron's energy remains after the collision? What happens if the neutron strikes a hydrogen atom ($m = m_n$)? Which material, carbon or hydrogen, is better at 'moderating' the neutrons?

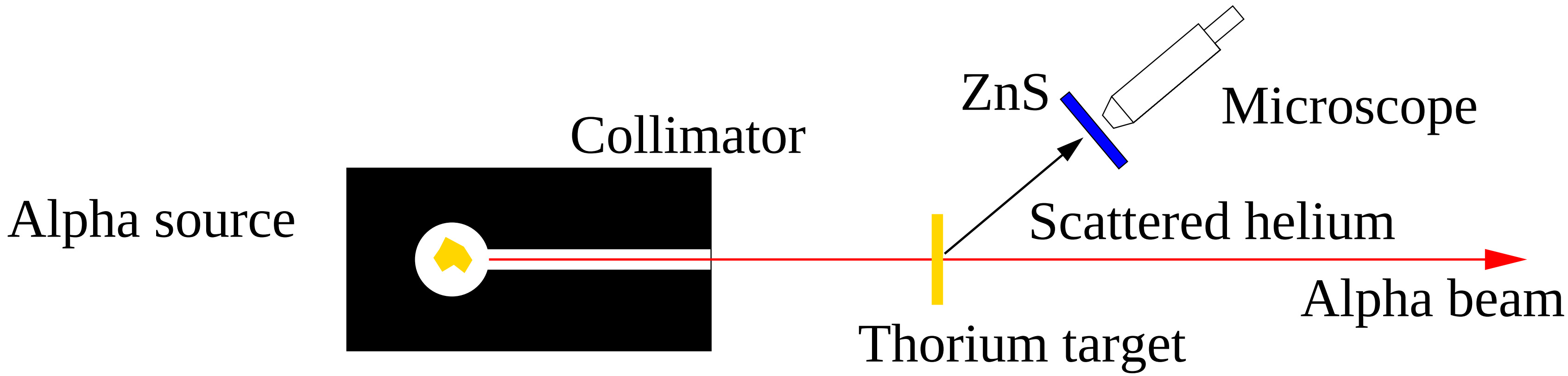


Nuclear Fission



Discovering the Atomic Nucleus

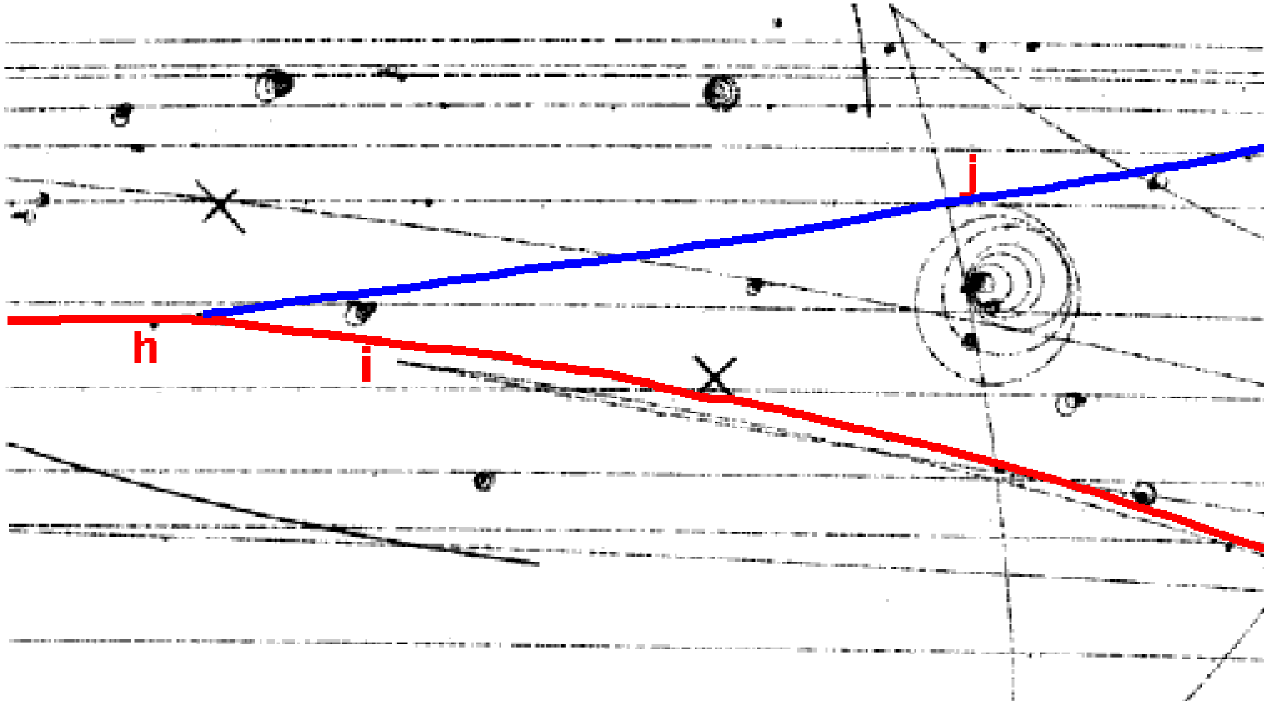
In the experiment that discovered the atomic nucleus Ernest Rutherford used a particle beam of $^4\mathrm{He}$ nuclei, each with an initial momentum of $1.08 \times 10^{-19}\ kg - m/s$ to scatter off a gold ($^{197}\mathrm{Au}$) target. His experimental setup is shown below. He found an abundance of scattered $^4\mathrm{He}$ at an angle of 10° to the original beam with a momentum of $4.31 \times 10^{-21}\ kg - m/s$, but observed no scattered gold nuclei. Where were the gold nuclei? What is the biggest angle the gold nuclei could reach? (Note: Any scattered particle had to make an angle of at least 4° with the beam to be observed because of the limitations of the apparatus.)



$$^{210}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{206}_{82}\mathrm{Pb}$$

More Nuclear Collisions

A $^{12}\mathrm{C}$ nucleus is fired at a $^{20}\mathrm{Ne}$ nucleus with a speed $v_0 = 2 \times 10^7\ m/s$. The scattered carbon nucleus is observed at an angle $\theta_c = 10^\circ$ and a speed $v_c = 1.6 \times 10^7\ m/s$. What is the speed and direction of the neon? Assume elastic scattering.



Looking For The Energy in the Sun

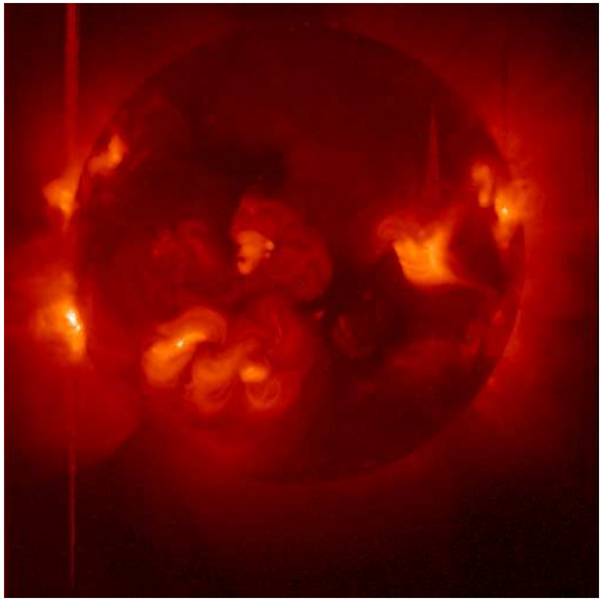
The energy source for our Sun is a series of nuclear reactions that burn protons as fuel. One of the steps is

$$^{1}\mathrm{H} \ + \ ^{2}\mathrm{H} \rightarrow \ ^{3}\mathrm{He} + \gamma$$

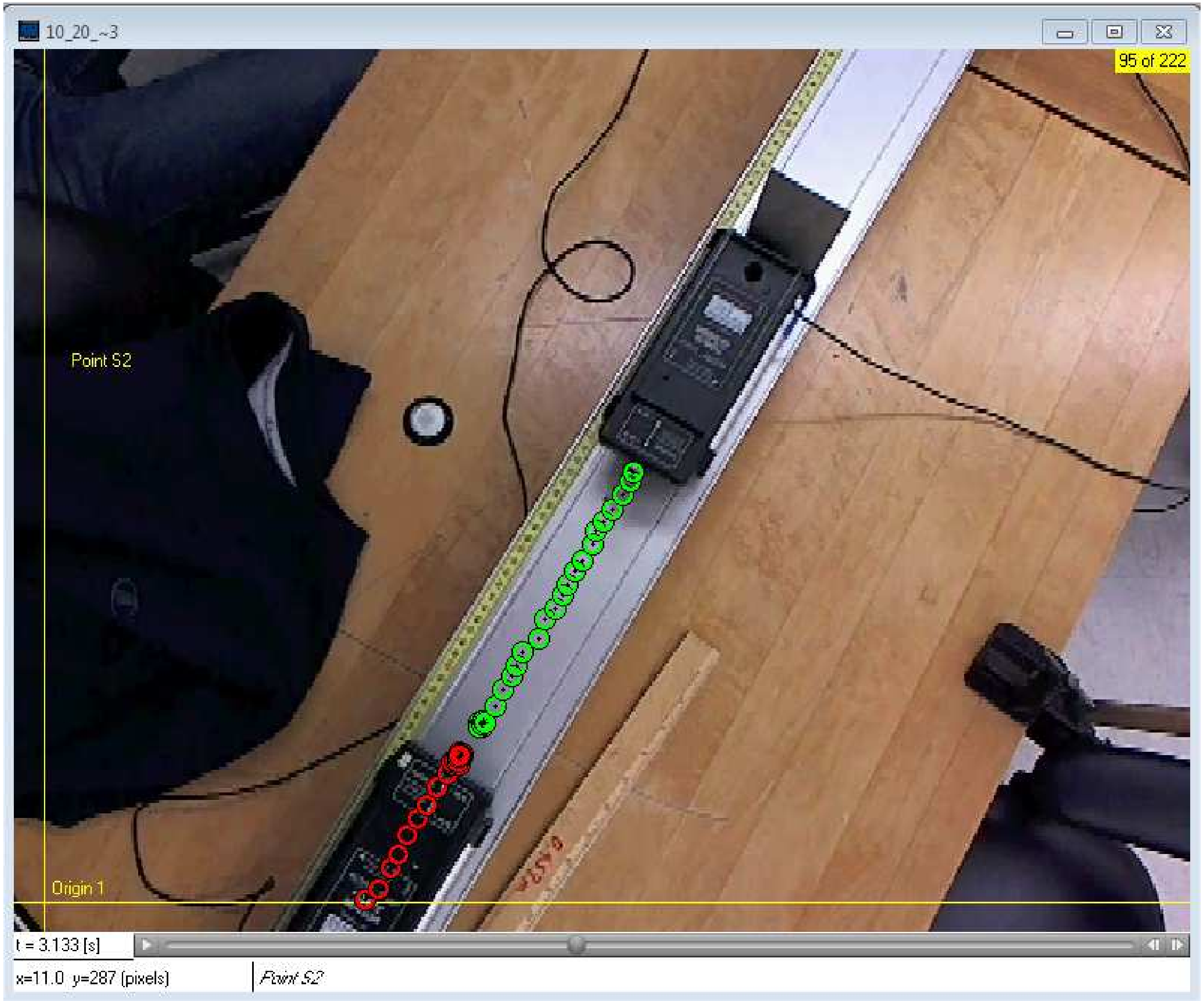
where γ is a photon, $^{3}\mathrm{He}$ is a helium-3 nucleus, and $^{2}\mathrm{H}$ is a deuteron. To occur, the proton and deuteron ($^{1}\mathrm{H}$) must touch so they have to approach within a distance $R = 2 \times 10^{-15} m$. The potential energy is

$$PE = U(r) = \frac{ke^2}{r}$$

where r is their center-to-center separation, e is the electronic charge, and $k = 8.99 \times 10^{9} Nm^2/C^2$. Consider a proton and deuteron within the Sun that start very far from each other and then follow a head-on collision course with energies $E_1 = 2 \times 10^{-17} J$ and $E_2 = 6 \times 10^{-17} J$, respectively. Do they get close enough to touch? What are their final energies long after the collision?



‘Proof’ of Newton’s Third Law



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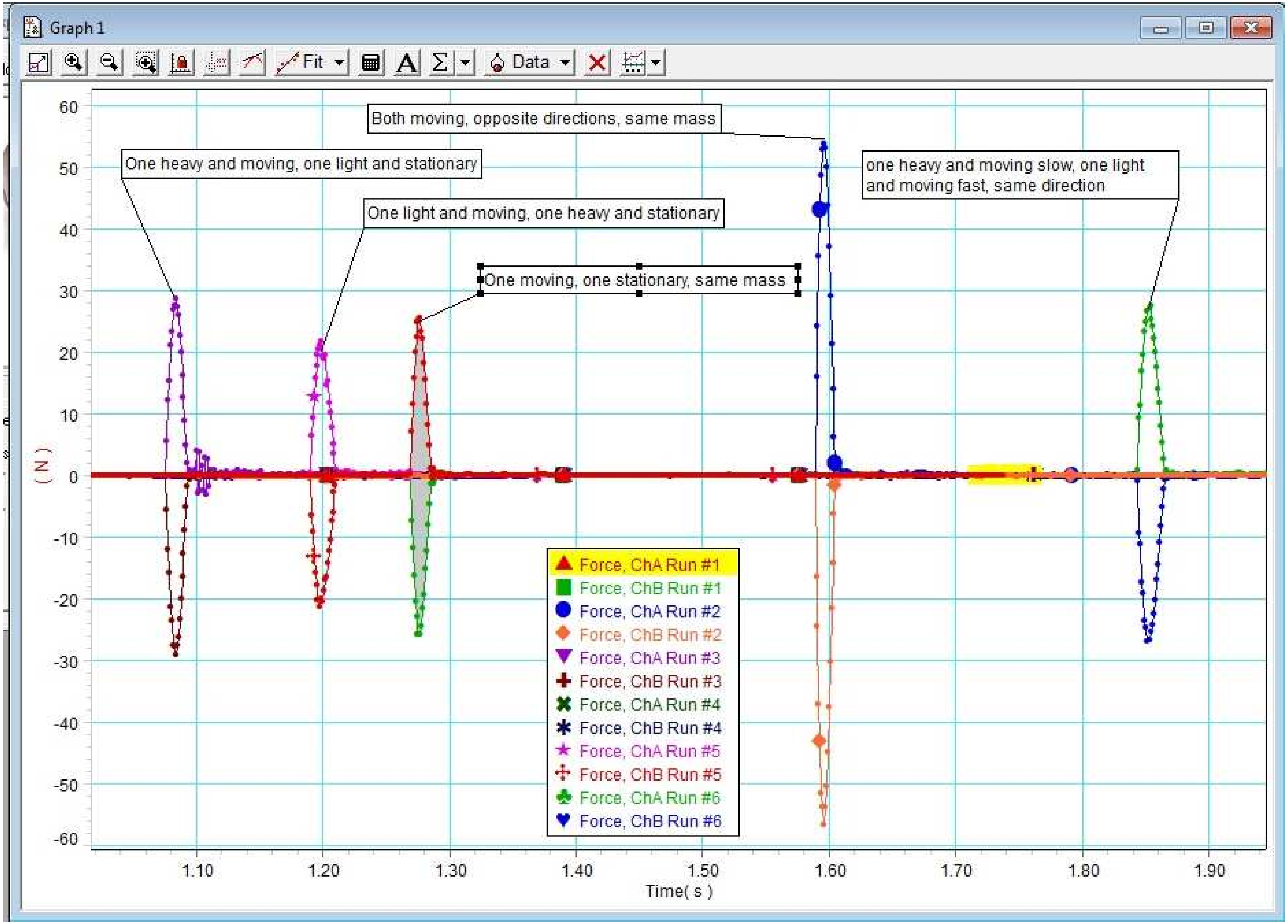
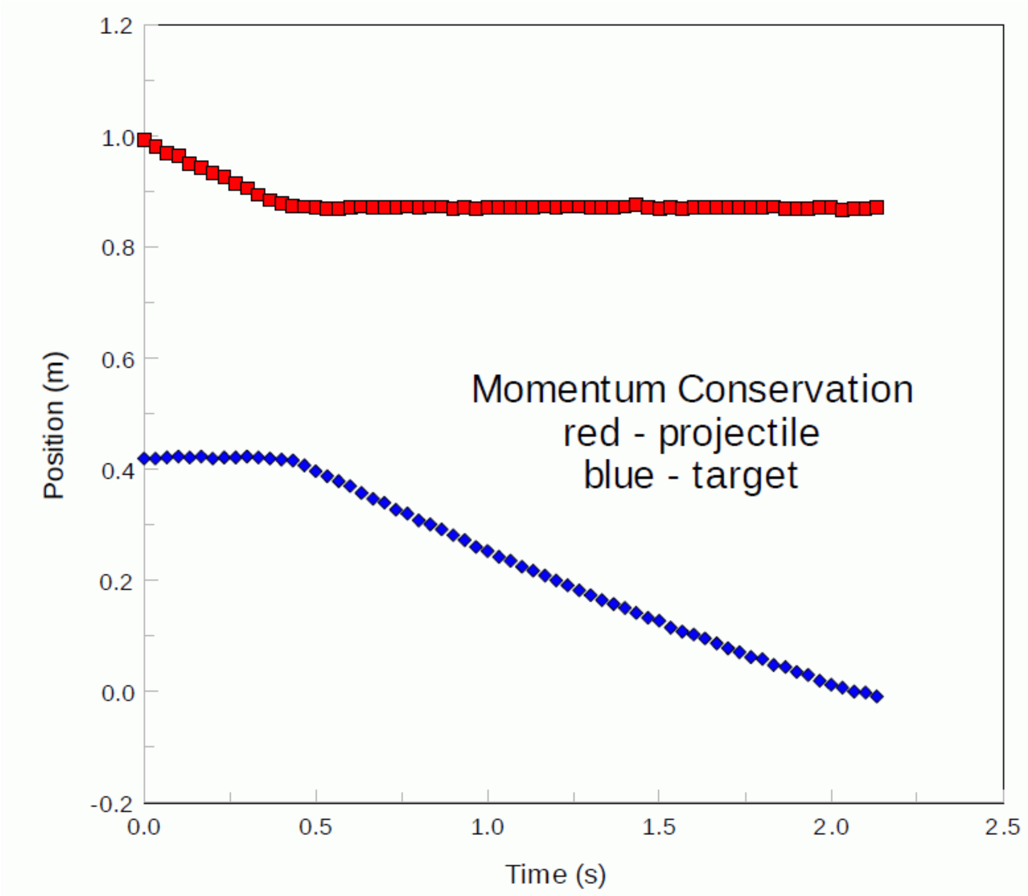


'Proof' of Momentum Conservation



For the projectile: $p_i = mv_i = 0.822\ kg \times -0.29\ m/s = 0.24\ kg - m/s$.

For the target: $p_f = mv_f = 0.831\ kg \times -0.27\ m/s = 0.22\ kg - m/s$.

$$\frac{\Delta p}{\langle p \rangle} = 0.09$$

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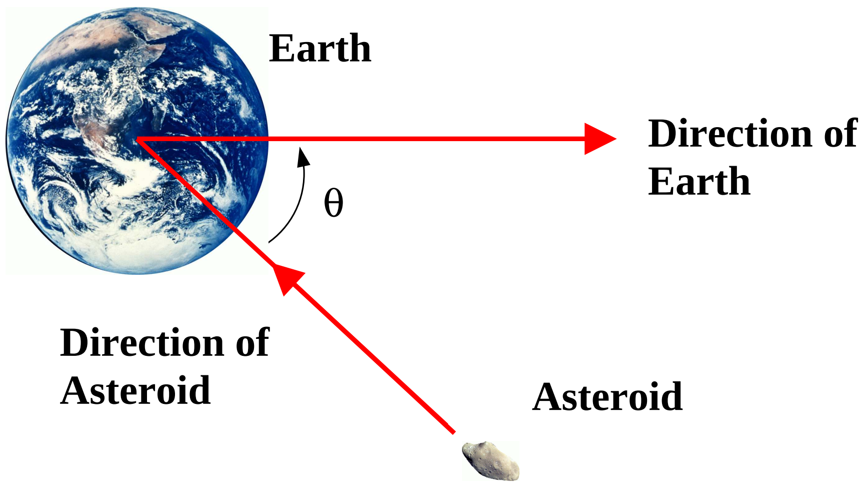
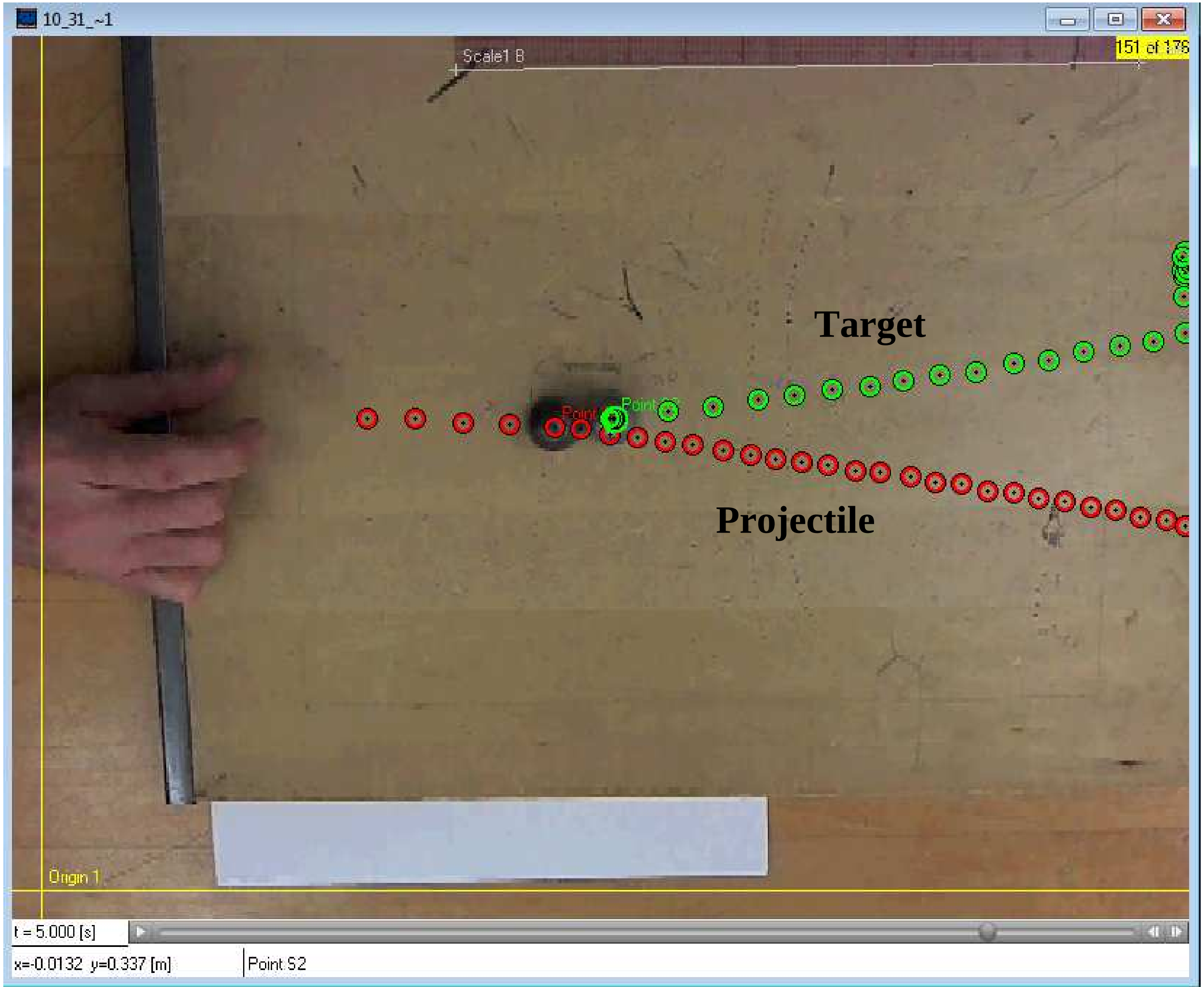
Angle:	$\theta = 30°$



Big Explosions

Event	Energy Released (J)	Fatalities
Hiroshima Atom Bomb (1945)	6.8×10^{13}	75,000 prompt, 250,000 delayed
Soviet Nuclear Test (1961)	2.7×10^{17}	None (that we know of)
Krakatoa Volcano (1883)	6.9×10^{18}	36,000
Tambora Volcano (1815)	Unknown	92,000

Analyzing the collision.



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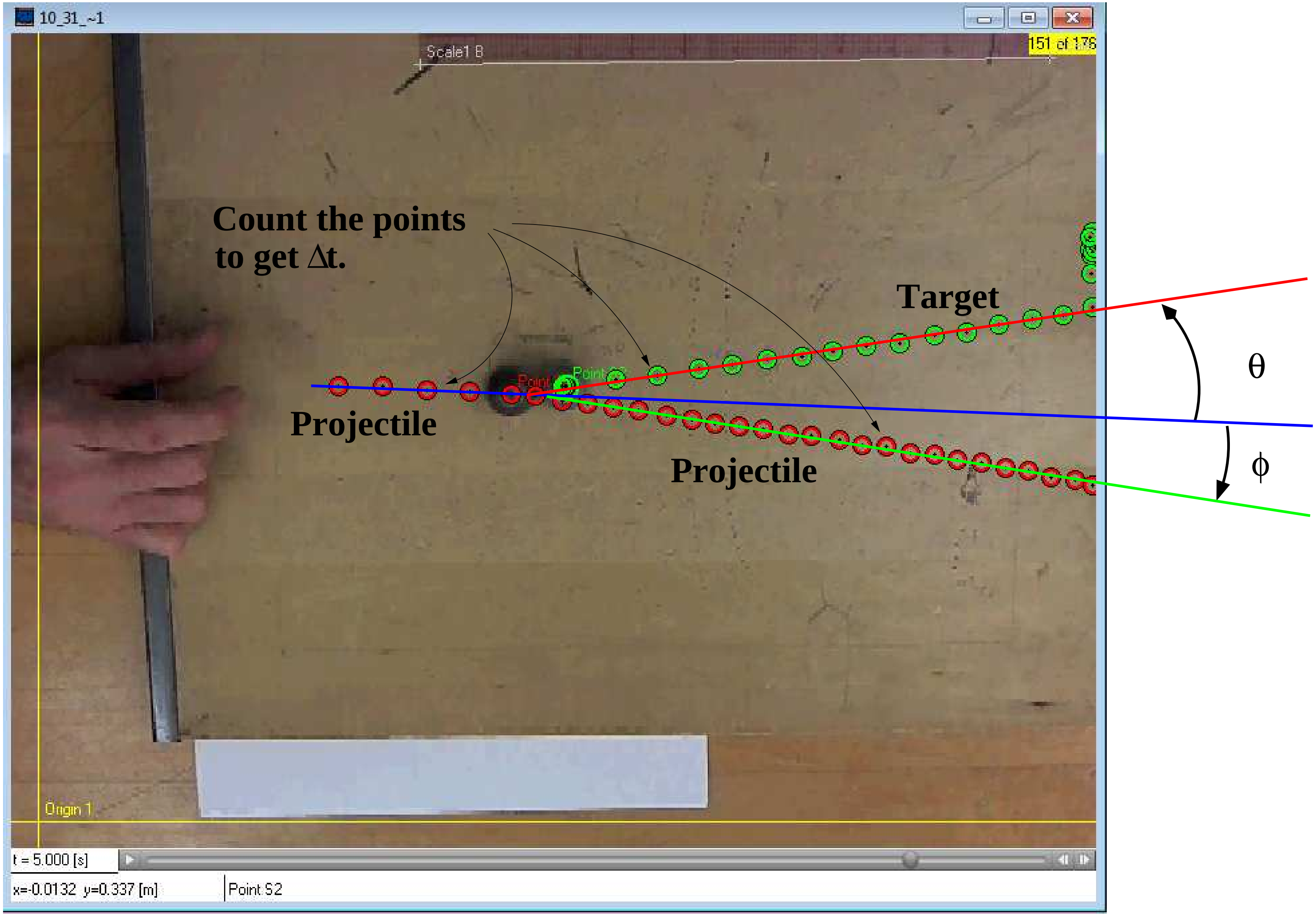

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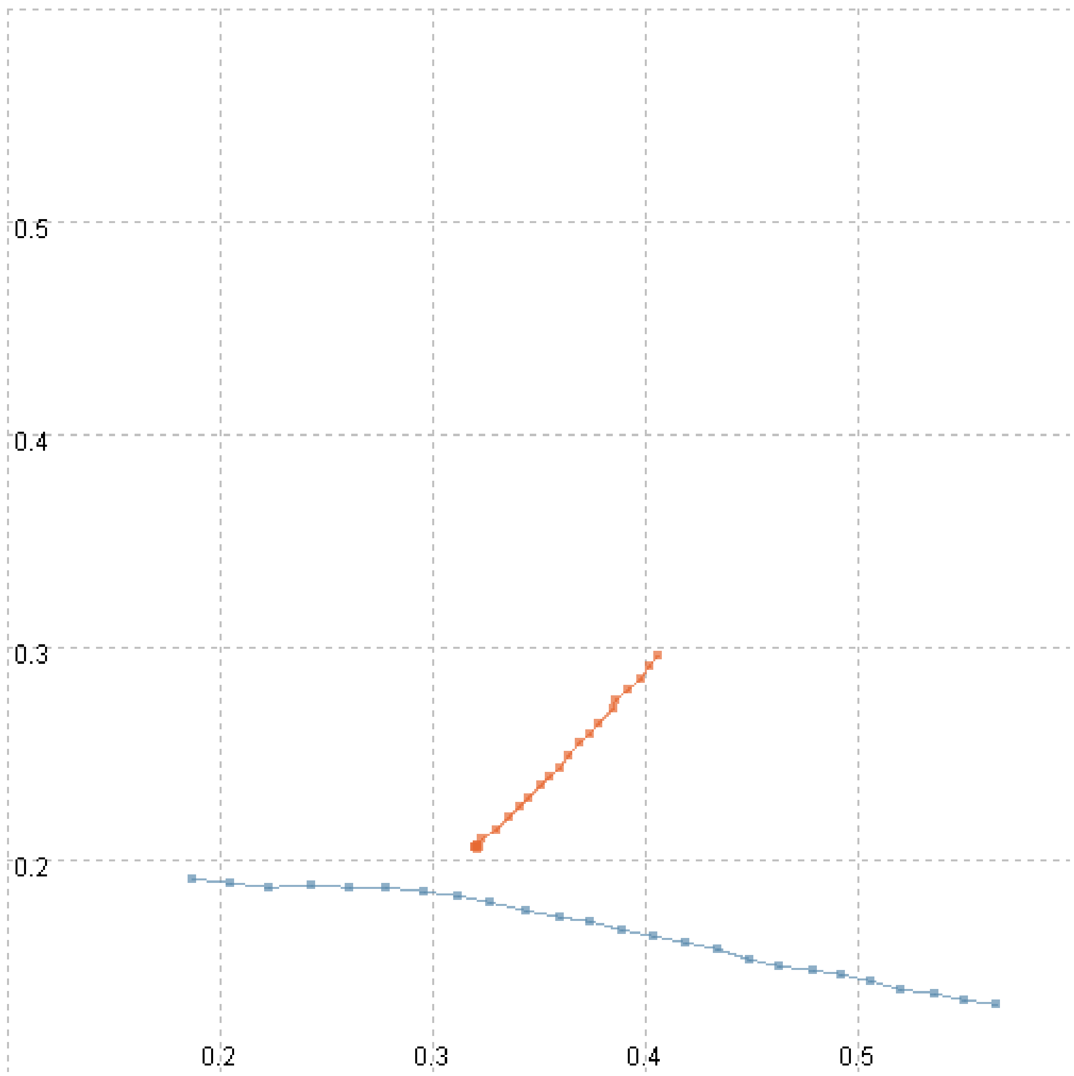

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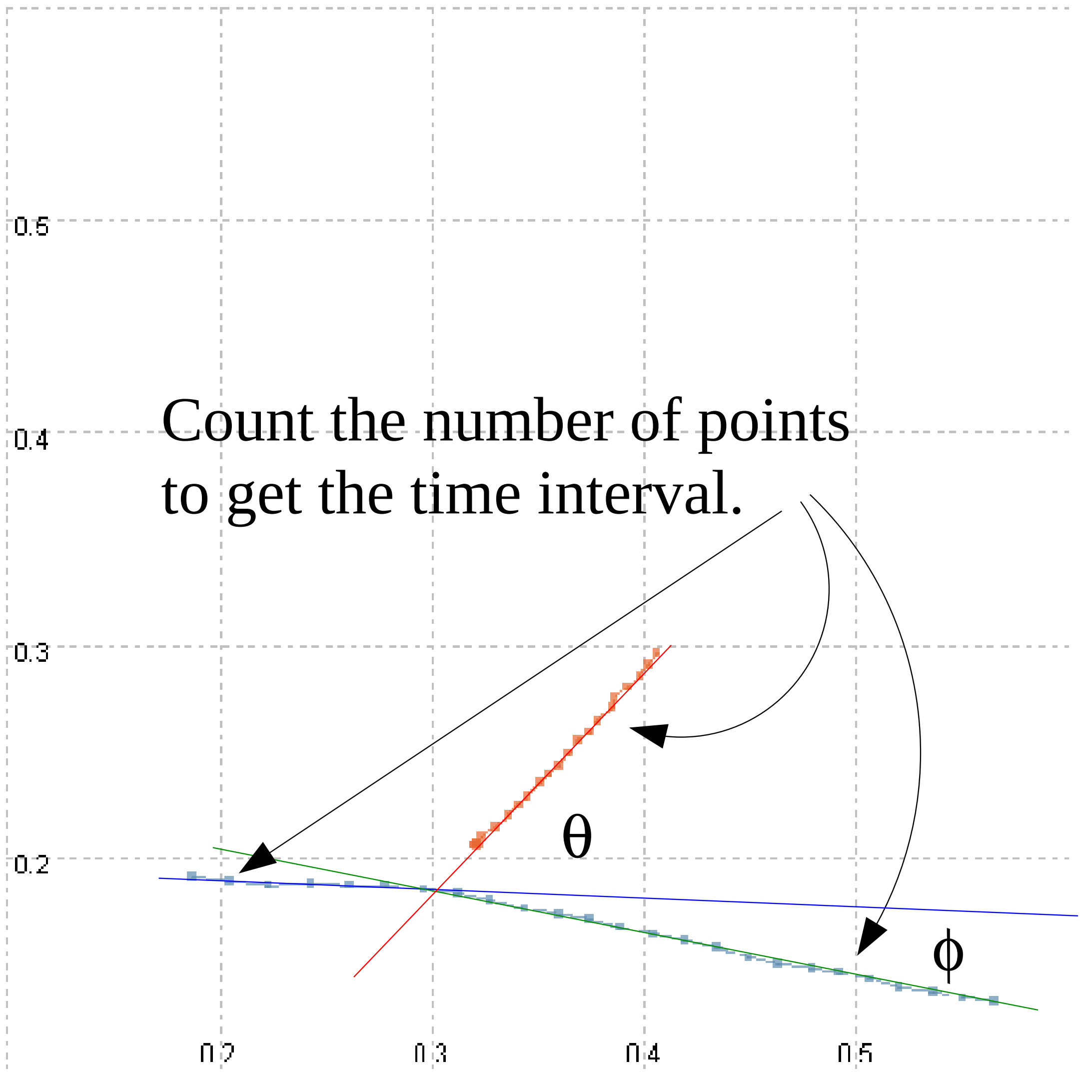

Making Plots with Aspect Ratio = 1

1. Collect the video data as normal, export your results to an Excel file, and then open that file in Excel.
2. In a web browser like Firefox go to ‘Graph Tools’ at `http://www.graphtools.com` and select line plot.
3. In the first group of options turn them all off (uncheck each box) EXCEPT the option to connect the points.
4. Set the ‘optional axis bounds’ so the difference between the minimum and maximum x and y values is the same.
5. Set the ‘size’ so the width and height is the same (500 pixels each).
6. Go back to your Excel spreadsheet and highlight the x and y data for your projectile (just the cells with the actual numbers) and enter cntrl-C to copy.
7. Go back to your ‘Graph Tools’ window and paste the data into the first data window by clicking in the data window and entering cntrl-V.
8. Repeat the last two steps for your target data.
9. Click ‘Submit Query’.
10. Print your plot.

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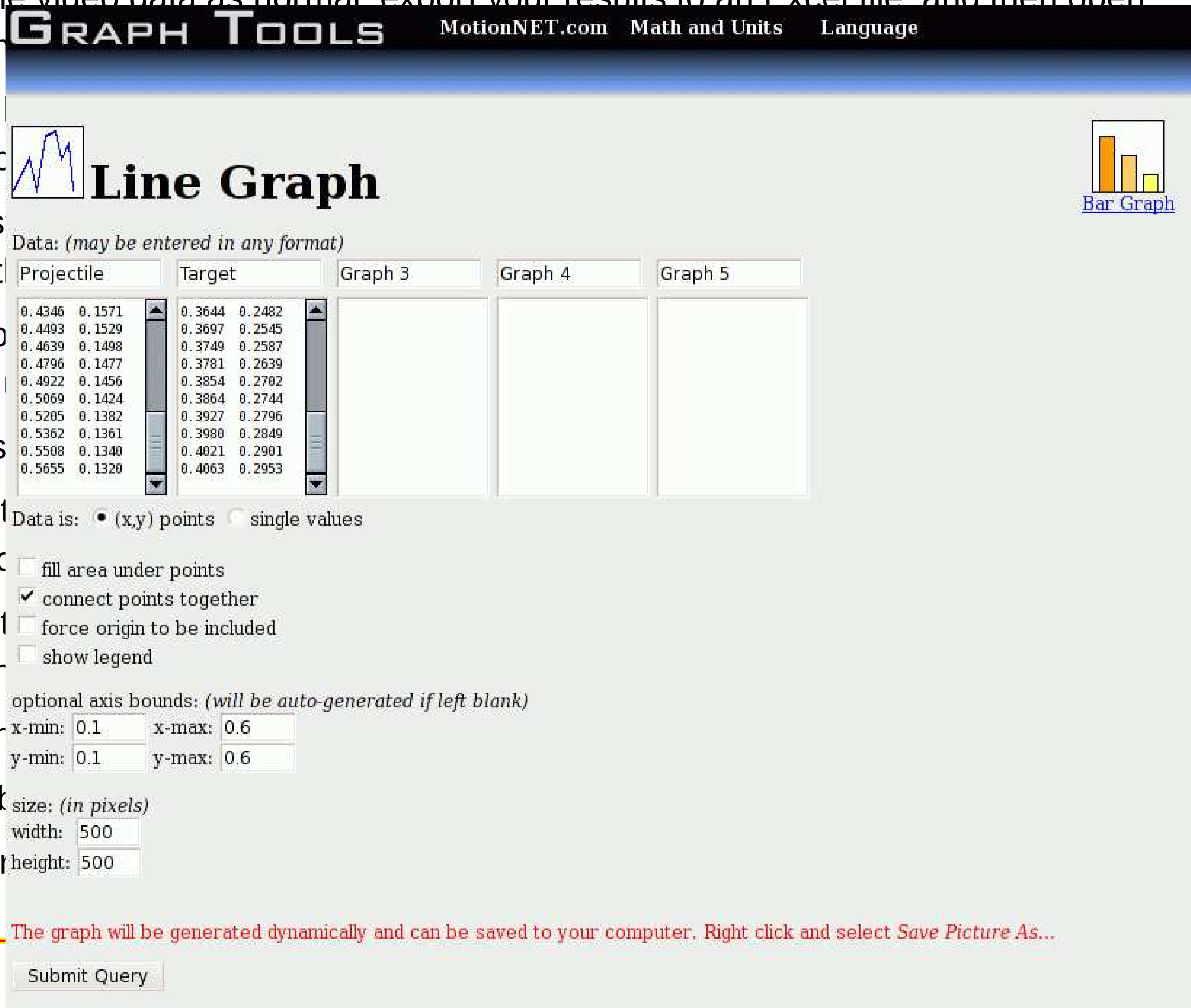

Making Plots with Aspect Ratio = 1

1. Collect the video data as normal, export your results to an Excel file, and then open that file in
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3. In the firs
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9. Click ‘Sul
10. Print your