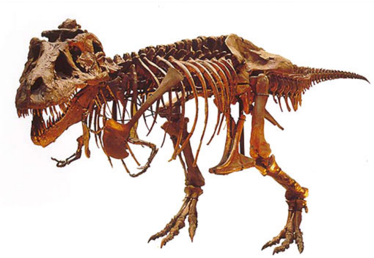
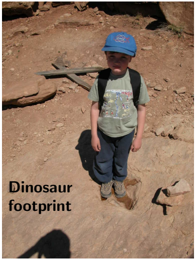
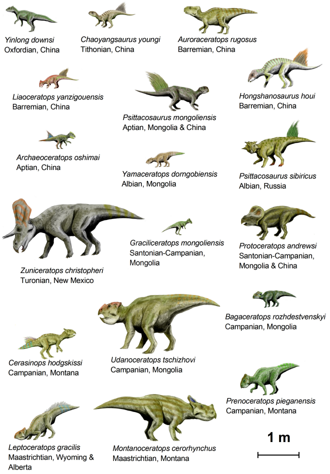
What Happened to the Dinosaurs? 1

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?

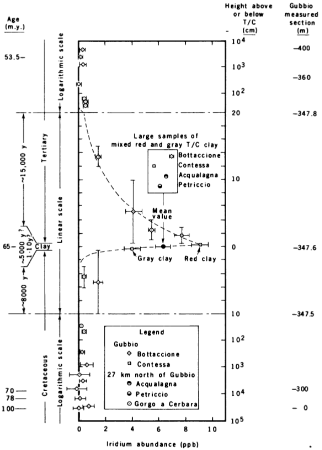






Evidence of an Asteroid Strike 2

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.

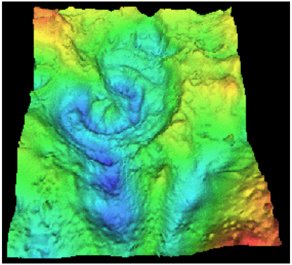


L.W.Alvarez, W.Alvarez, F.Asaro, H.V.Michel, *Science*, "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction", 208 (1980) 1095.

More Evidence (and What to Worry About) 3

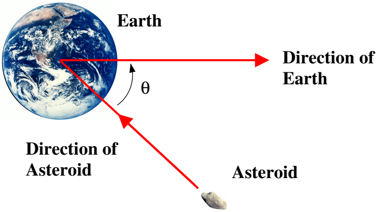
1. An impact crater of the right size and age has been found on the Yucatan Peninsula in Mexico showing signs of shocked crystals and melted rock.
2. There is abundant evidence of other cataclysmic collisions with Solar System debris.
3. Frequency of impacts:

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

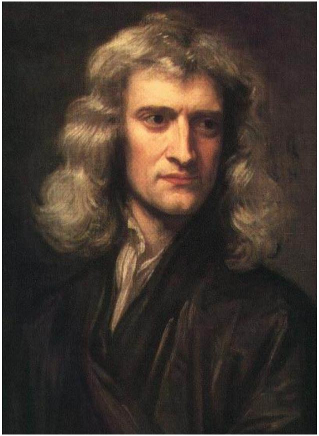


It is now believed the dinosaurs and many other species were driven to extinction 65 million years ago by an ecological disaster brought on by the collision of an asteroid with the Earth. Consider the following scenario. The asteroid collides with the Earth as the Earth orbits the Sun and sticks to the 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 (6.8×10^{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:	$\theta = 30^\circ$



1. Consider a body with no net force acting on it. If it is at rest it will remain at rest. If it is moving with a constant velocity it will continue to move at that velocity.
2. For all the different forces acting on a body
$$\Sigma \vec{F}_i = m\vec{a}$$
3. For every action there is an equal and opposite reaction.
$$\vec{F}_{AB} = -\vec{F}_{BA}$$



Newton's Laws 6

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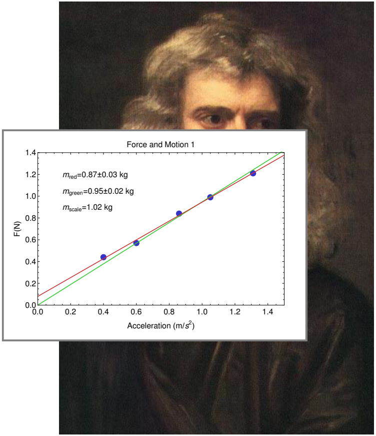
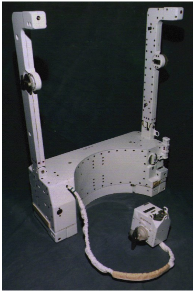


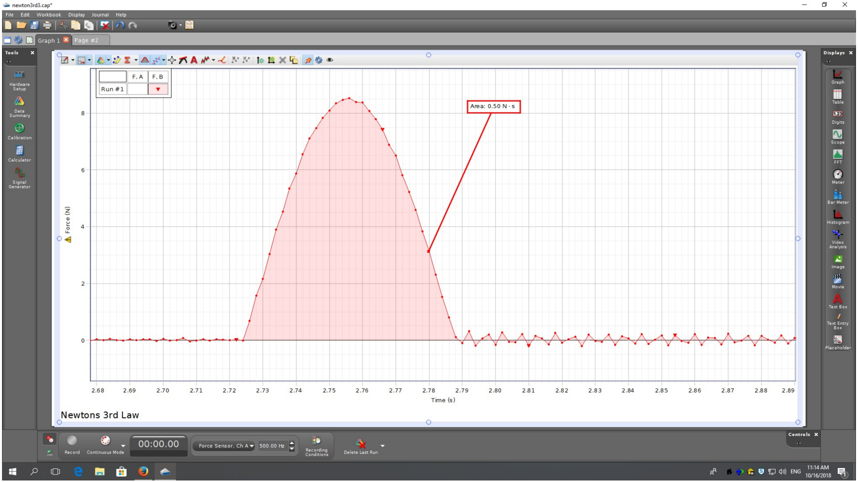
The Simplified Aid For EVA Rescue (SAFER) is a jetpack used to recover International Space Station (ISS) astronauts in the event of a "man/woman overboard". Astronauts are usually connected to the ISS by a tether, but if an astronaut becomes untethered and floats away, SAFER would fly back to the station. It uses small nitrogen-gas-jet thrusters. The SAFER carries a mass of nitrogen $m_n = 1.4\ kg$ which is ejected at a speed $v_n = 440\ m/s$. The total mass of the astronaut and spacesuit at the start of an EVA is $m_{ss} = 205\ kg$. If the astronaut is a kilometer away from the ISS with 10 minutes of oxygen left, will the SAFER get them back to the ISS in time?

Astronaut Mark Lee tests SAFER on STS-64.

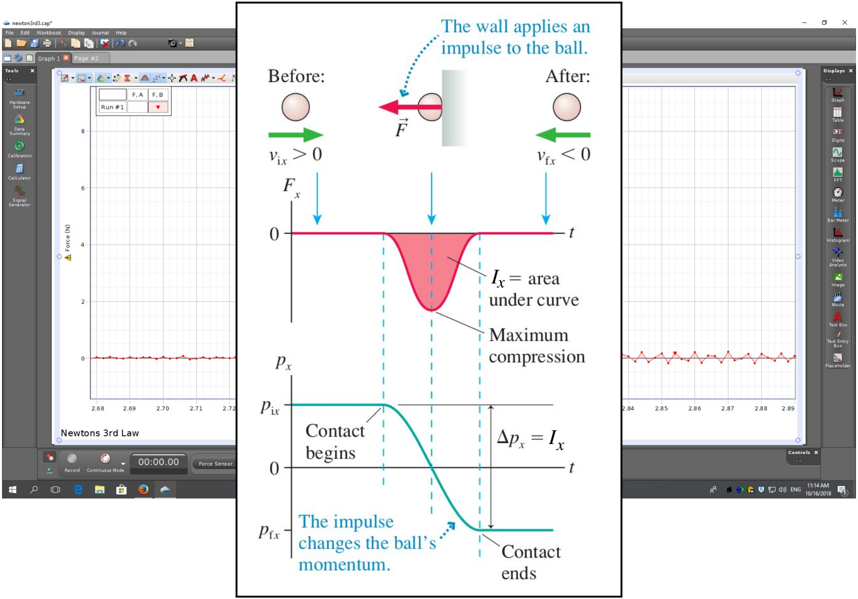


SAFER backpack.

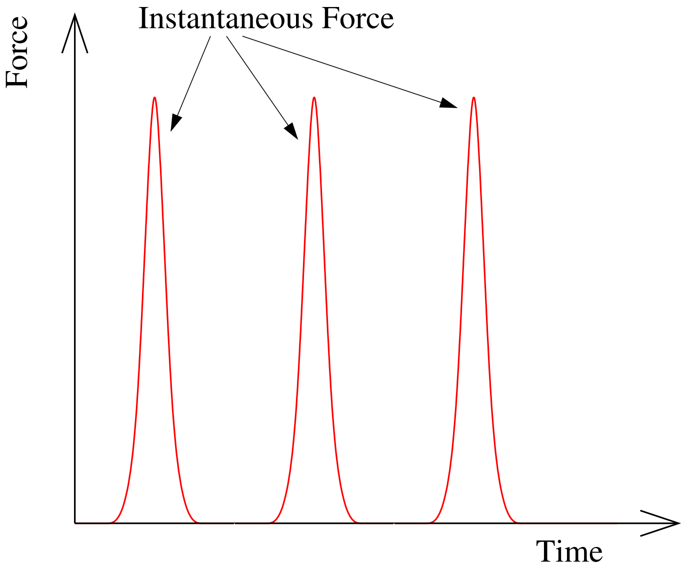
Impulse and Momentum Change 8



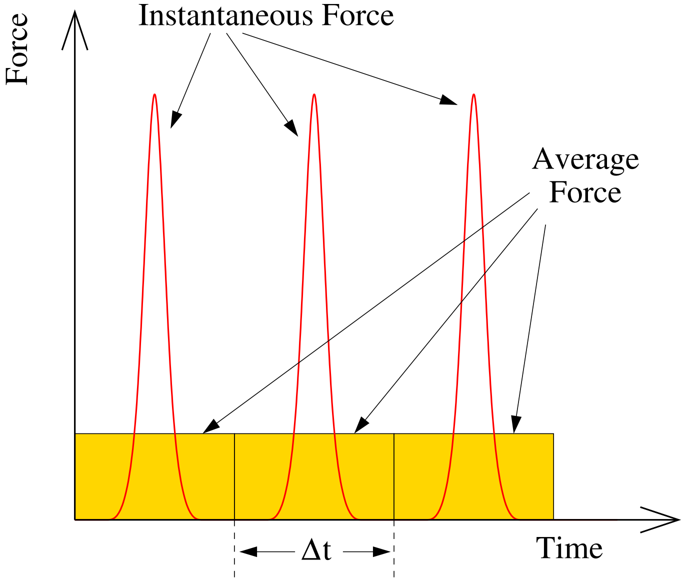
Impulse and Momentum Change 9



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.

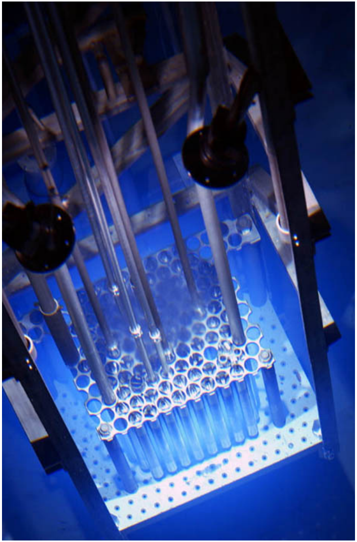

Instantaneous Force
Force
Time

Instantaneous versus Average Force 12



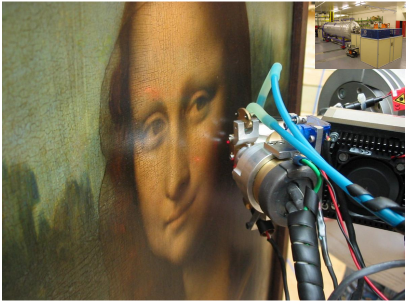
In a nuclear reactor heavy atomic nuclei like uranium are irradiated with neutrons which cause them to split apart ('to fission'); releasing energy that can be used to make electricity. A byproduct of the fission event is additional neutrons that can cause further fissions and energy release. However, 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.

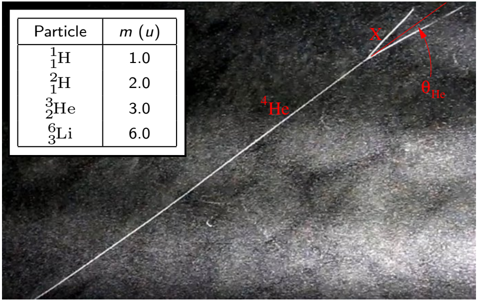
One of these too-fast neutrons ($m_n = 1\ u$) makes an elastic, head-on collision with the nucleus of a carbon atom ($m_c = 12\ u$) at rest. The initial kinetic energy of the neutron is $E_0 = 1\ \mathrm{MeV}$. What fraction of the neutron's energy remains after the collision?



Nuclear Collisions and the Liberal Arts 14

Nuclear collisions are useful diagnostic tools to identify components of a material. In the picture to the left below, an accelerator at the Louvre in Paris is used to study the properties of a painting you might recognize for preservation and cultural purposes. A beam of ${}^4_2\mathrm{He}$ nuclei (mass $m_{He} = 4.0\ u$) is incident on the painting with a speed $v_0 = 4 \times 10^7\ m/s$ and scatter off a nucleus in the 'target'. The figure on the right shows a similar scattering event in a cloud chamber to help visualize what is happening. The scattered ${}^4_2\mathrm{He}$ nucleus is observed at an angle $\theta_{He} = 8^\circ$ relative to its original direction and a speed $v_{He} = 2.4 \times 10^7\ m/s$. The recoiling particle (the other track in the picture) is found to have a velocity $v_X = 6.4 \times 10^7\ m/s$. What is the mass and direction of particle X? What is the particle? Some candidates are in the table. Assume elastic scattering.





Particle	m (u)
${}^1_1\mathrm{H}$	1.0
${}^2_1\mathrm{H}$	2.0
${}^3_2\mathrm{He}$	3.0
${}^6_3\mathrm{Li}$	6.0

Looking For The Energy in the Sun

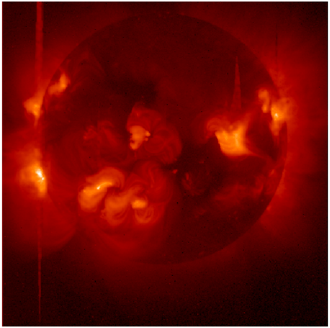
The energy source for our Sun is a series of nuclear reactions that burn protons as fuel. One of the steps is

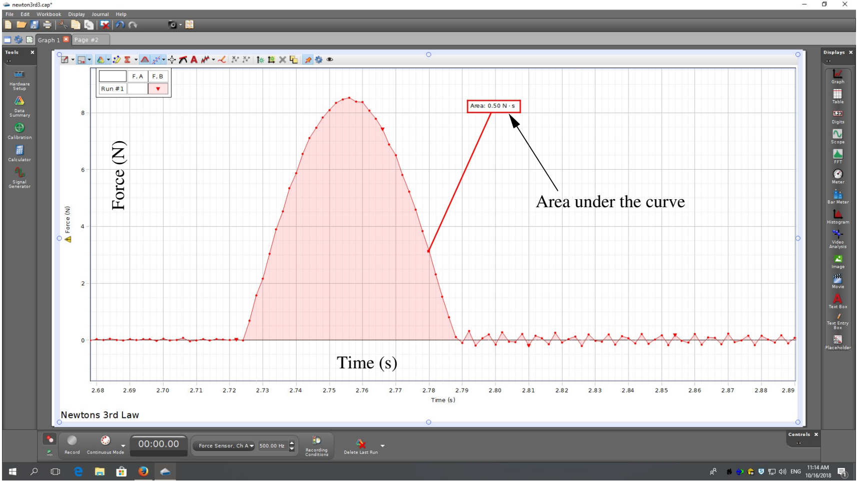
$$^{1}\mathrm{H} \; + \; ^{2}\mathrm{H} \rightarrow \; ^{3}\mathrm{He} + \gamma$$

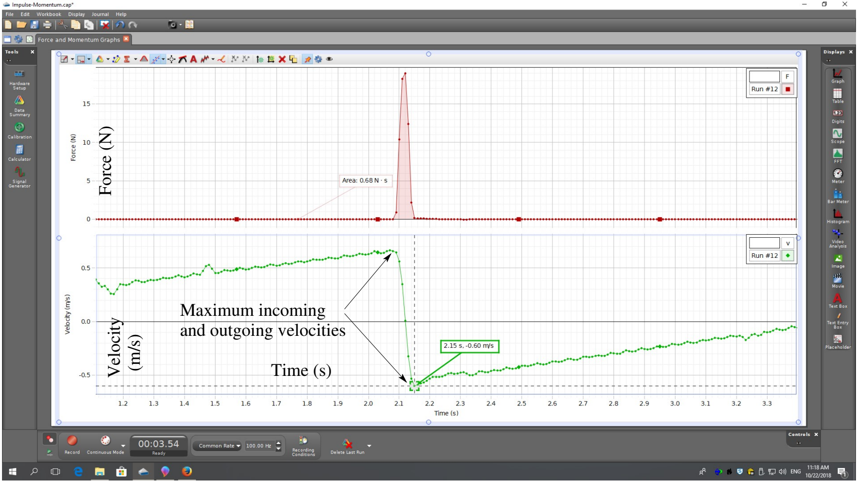
where γ is a photon, $^{3}\mathrm{He}$ is a helium-3 nucleus, and $^{2}\mathrm{H}$ is a deuteron. To occur, the proton and deuteron ($^{1}\mathrm{H}$) must touch so they have to approach within a distance $R = 2 \times 10^{-15} m$. The potential energy is

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

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?

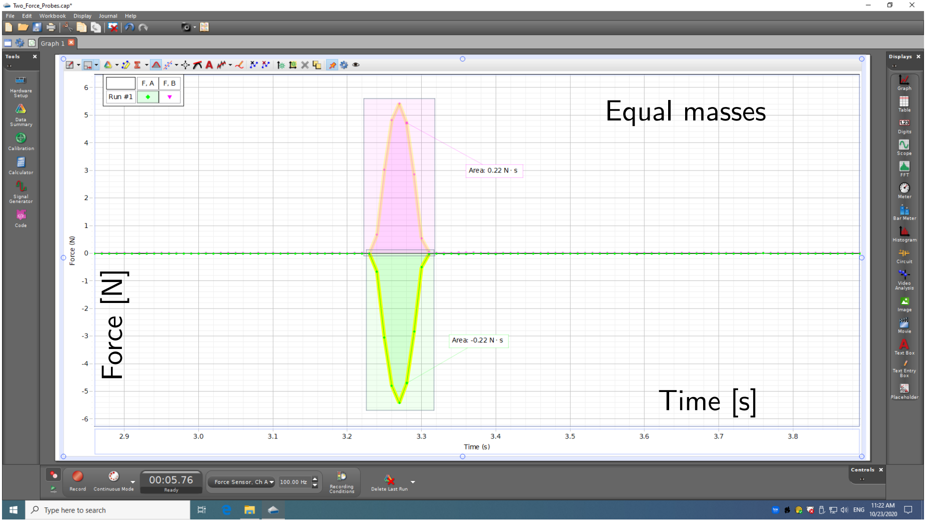



Area: 0.50 N · s
Force (N)
Area under the curve
Time (s)
Newtons 3rd Law



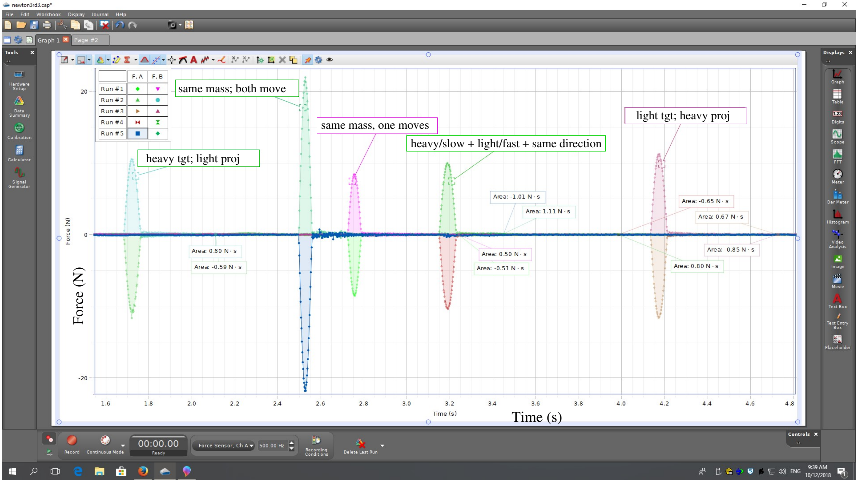
Impulse-Momentum.cap*
File Edit Workbook Display Journal Help
Force and Momentum Graphs
Force (N)
Run #12
Area: 0.68 N · s
Maximum incoming
and outgoing velocities
Velocity (m/s)
Time (s)
2.15 s, -0.60 m/s
00:03.54
Record
Continuous Mode
Common Rate
100.00 Hz
Delete Last Run

1. When you collide the carts use the magnetic repulsion to bounce the carts (not the spring-loaded plungers).
2. Be gentle.
3. In Activity 5.f extract $\Delta p = p_f - p_i$ and $\%Diff = (p_f - p_i)/\langle p \rangle$ from your data and compile your results with the rest of the class.
4. Take the video with the Capstone app.
    1. Open `Phys131` folder.
    2. Double-click `Video Capture.cap`
    3. Click `No` to all the requests add a Force Sensor.
    4. To record a video click the red circle in the upper-left corner of the Capstone gui.
    5. Click the same button as the previous step to stop recording.
    6. To save the video right-click the mouse when you hover over the video gui and select "`Save Movie as ...`".

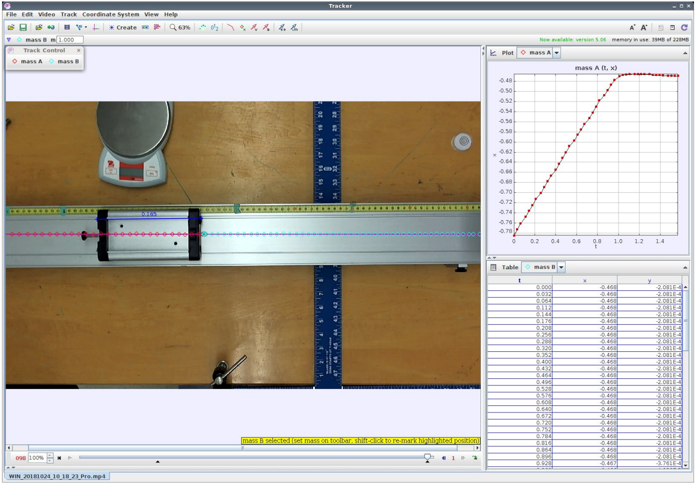


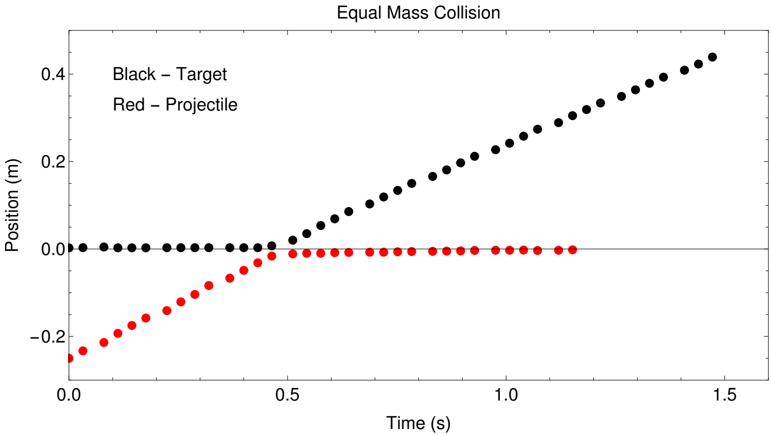
Equal masses
Force [N]
Time [s]
Area: 0.22 N · s
Area: -0.22 N · s
F, A
F, B
Run #1
Force (N)
Time (s)

'Proof' of Newton's Third Law



‘Proof’ of Newton’s Third Law 21





For the projectile: $p_i = mv_i = 0.52\ kg \times 0.51\ m/s = 0.26\ kg - m/s$.
For the target: $p_f = mv_f = 0.52\ kg \times 0.43\ m/s = 0.23\ kg - m/s$.

$$\frac{\Delta p}{\langle p \rangle} = 0.12$$

The End of the Dinosaurs 23

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 ($6.8 \times 10^{13}\ J$)?

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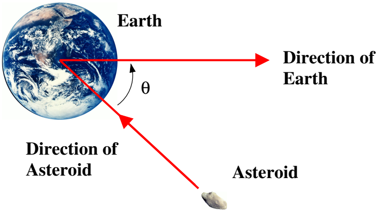


What would happen now?

Effect of 5-km-wide asteroid striking the mid-Atlantic.

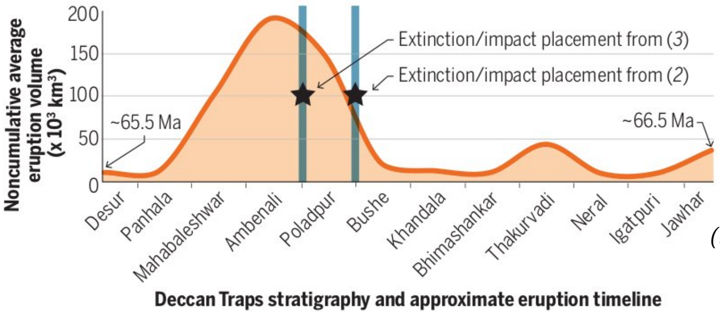
Watch

Effects of the Chicxulub Asteroid Strike 25

1. Megatsunamis as high as 5 kilometers (3.1 mi); enough to completely inundate even large islands such as Madagascar.
2. Excavated material along with pieces of the impactor, ejected out of the atmosphere by the blast, would have been heated to incandescence upon re-entry, broiling the Earth's surface and possibly igniting wildfires.
3. Colossal shock waves would have triggered global earthquakes and volcanic eruptions.
4. The emission of dust and particles could have covered the entire surface of the Earth for years, possibly a decade. Photosynthesis by plants would be interrupted, affecting the entire food chain.
5. Sunlight would have been blocked from reaching the surface of the earth by the dust particles in the atmosphere, cooling the surface dramatically.
6. It is estimated that 75% or more of all species on Earth vanished.

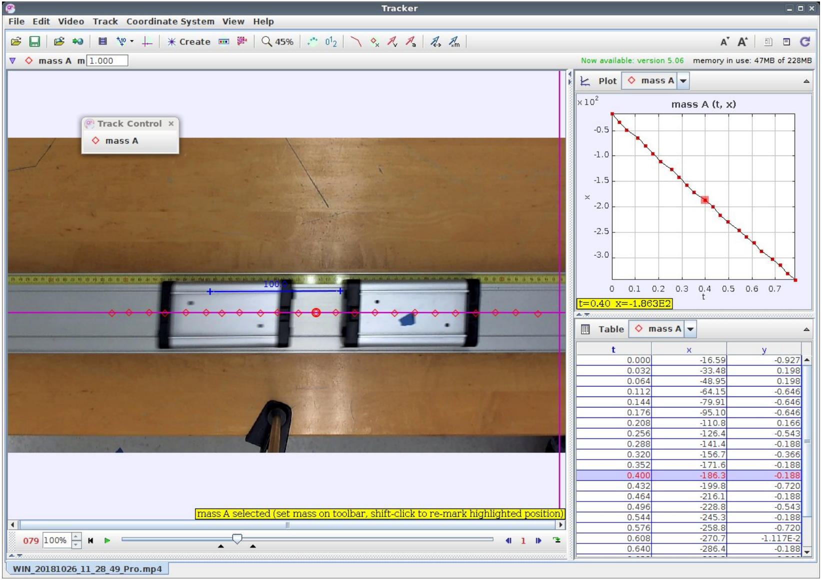
Event	Energy Released (J)	Fatalities
Hiroshima Atom Bomb (1945)	6.8×10^{13}	90,000-120,000 prompt
Nagasaki Atom Bomb (1945)	10.2×10^{13}	60,000-80,000 prompt
Tokyo fire raids (1945)	N/A	88,000-125,000 prompt
Soviet Nuclear Test (1961)	2.7×10^{17}	None (that we know of)
Krakatoa Volcano (1883)	6.9×10^{18}	36,000
Tambora Volcano (1815)	Unknown	92,000

⟵ Time

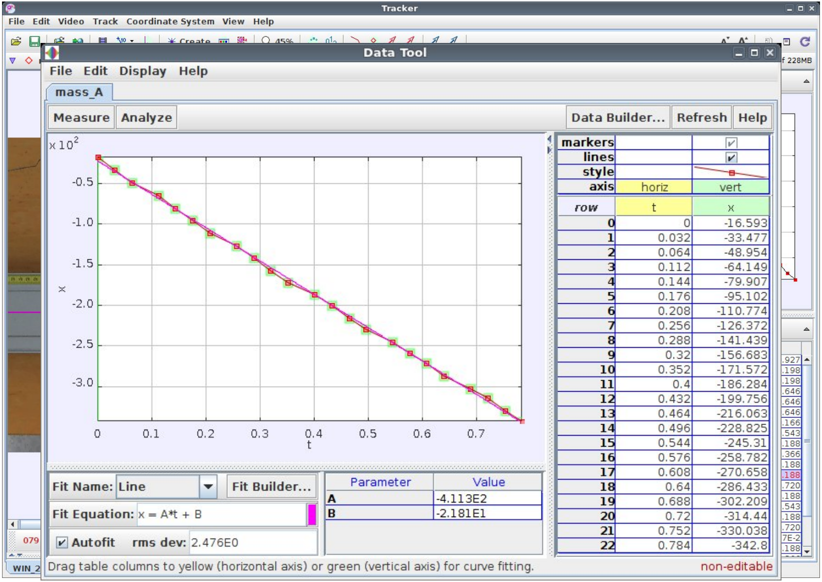


(1)

1. S. Burgess, *Science*, **363**, 815 (2019).
2. C. J. Sprain *et al.*, *Science* **363**, 866 (2019).
3. B. Schoene *et al.*, *Science* **363**, 862 (2019).


Tracker
File Edit Video Track Coordinate System View Help
Create
45%
mass A m 1.000
Now available: version 5.06 memory in use: 47MB of 228MB
Track Control
mass A
100.0
mass A selected (set mass on toolbar, shift-click to re-mark highlighted position)
079 100%
1
WIN_20181026_11_28_49_Pro.mp4
Plot mass A
x 10²
mass A (t, x)
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
x
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
t
t=0.40 x=-1.863E2
Table mass A
t x y
0.000 -16.59 -0.927
0.032 -33.48 0.198
0.064 -48.95 0.198
0.112 -64.15 -0.646
0.144 -79.91 -0.646
0.176 -95.10 -0.646
0.208 -110.8 0.166
0.256 -126.4 -0.543
0.288 -141.4 -0.188
0.320 -156.7 -0.366
0.352 -171.6 -0.188
0.400 -186.3 -0.188
0.432 -199.8 -0.720
0.464 -216.1 -0.188
0.496 -228.8 -0.543
0.544 -245.3 -0.188
0.576 -258.8 -0.720
0.608 -270.7 -1.117E-2
0.640 -286.4 -0.188

Center-of-Mass Motion - Equal Massses



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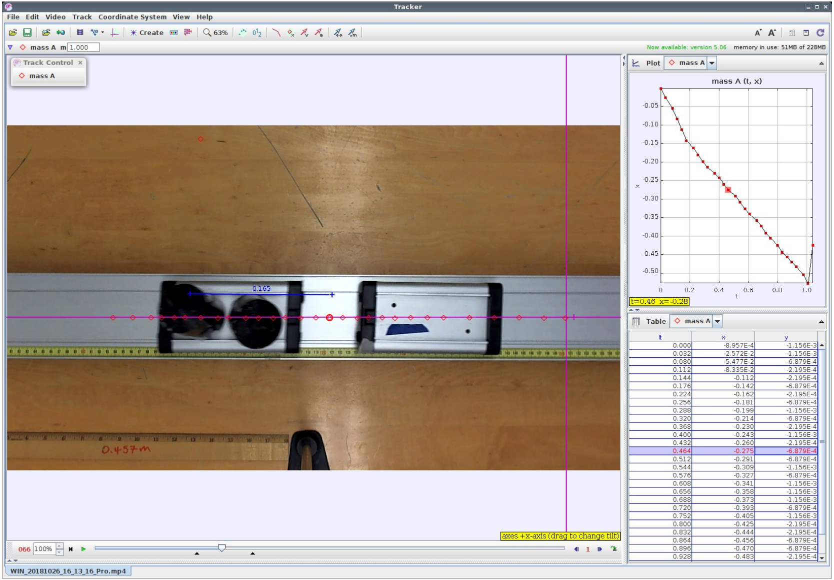
2	0.064	-48.954
3	0.112	-64.149
4	0.144	-79.907
5	0.176	-95.102
6	0.208	-110.774
7	0.256	-126.372
8	0.288	-141.439
9	0.32	-156.683
10	0.352	-171.572
11	0.4	-186.284
12	0.432	-199.756
13	0.464	-216.063
14	0.496	-228.825
15	0.544	-245.31
16	0.576	-258.782
17	0.608	-270.658
18	0.64	-286.433
19	0.688	-302.209
20	0.72	-314.44
21	0.752	-330.038
22	0.784	-342.8

Parameter	Value
A	-4.113E2
B	-2.181E1



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0.032	-2.572E-2	-1.156E-3
0.080	-5.477E-2	-6.879E-4
0.112	-8.335E-2	-2.195E-4
0.144	-0.112	-2.195E-4
0.176	-0.142	-6.879E-4
0.224	-0.162	-2.195E-4
0.256	-0.181	-6.879E-4
0.288	-0.199	-1.156E-3
0.320	-0.214	-6.879E-4
0.368	-0.230	-2.195E-4
0.400	-0.243	-1.156E-3
0.432	-0.260	-2.195E-4
0.464	-0.275	-6.879E-4
0.512	-0.291	-6.879E-4
0.544	-0.309	-1.156E-3
0.576	-0.327	-6.879E-4
0.608	-0.341	-1.156E-3
0.656	-0.358	-1.156E-3
0.688	-0.373	-1.156E-3
0.720	-0.393	-6.879E-4
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0.800	-0.425	-2.195E-4
0.832	-0.444	-2.195E-4
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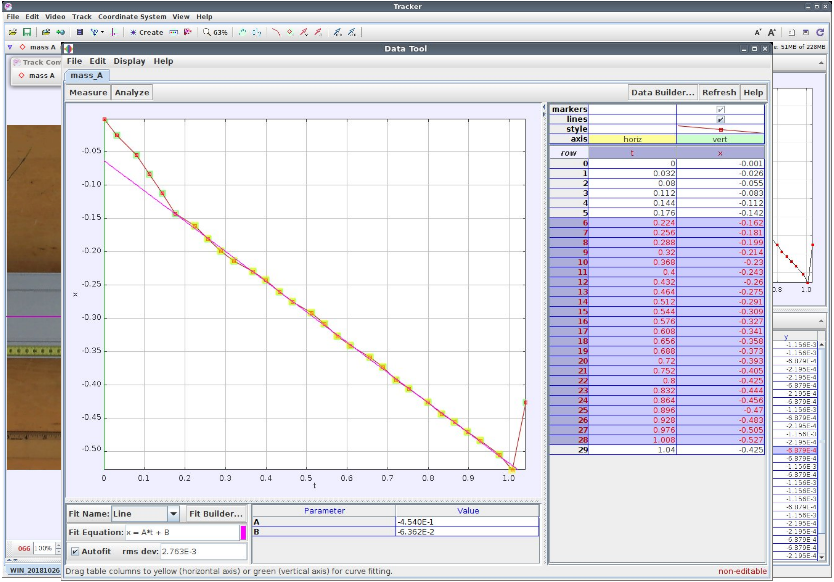
0.928	-0.483	-2.195E-4


Tracker
File Edit Video Track Coordinate System View Help
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File Edit Display Help
mass_A
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row t x
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1 0.032 -0.026
2 0.08 -0.055
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9 0.32 -0.214
10 0.368 -0.23
11 0.4 -0.243
12 0.432 -0.26
13 0.464 -0.275
14 0.512 -0.291
15 0.544 -0.309
16 0.576 -0.327
17 0.608 -0.341
18 0.656 -0.358
19 0.688 -0.373
20 0.72 -0.393
21 0.752 -0.405
22 0.8 -0.425
23 0.832 -0.444
24 0.864 -0.456
25 0.896 -0.47
26 0.928 -0.483
27 0.976 -0.505
28 1.008 -0.527
29 1.04 -0.425
Fit Name: Line
Fit Builder...
Fit Equation: x = A*t + B
Autofit rms dev: 2.763E-3
Parameter Value
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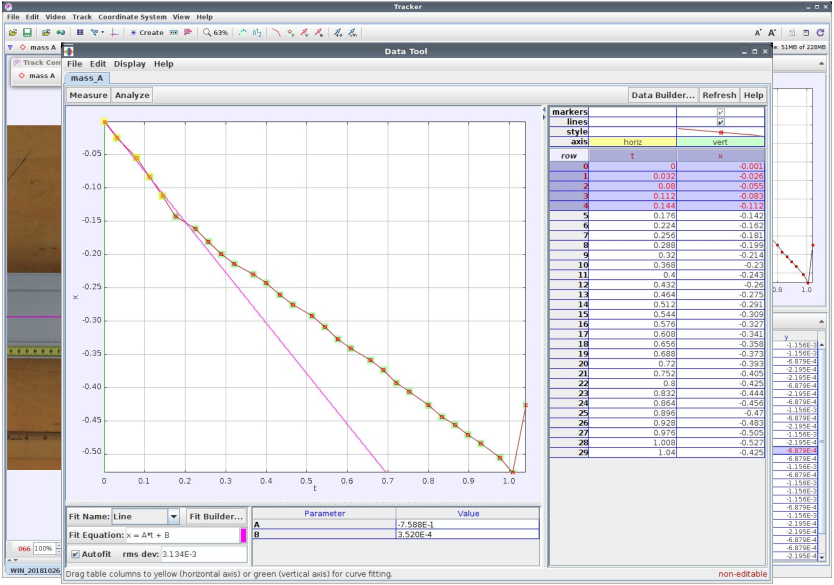
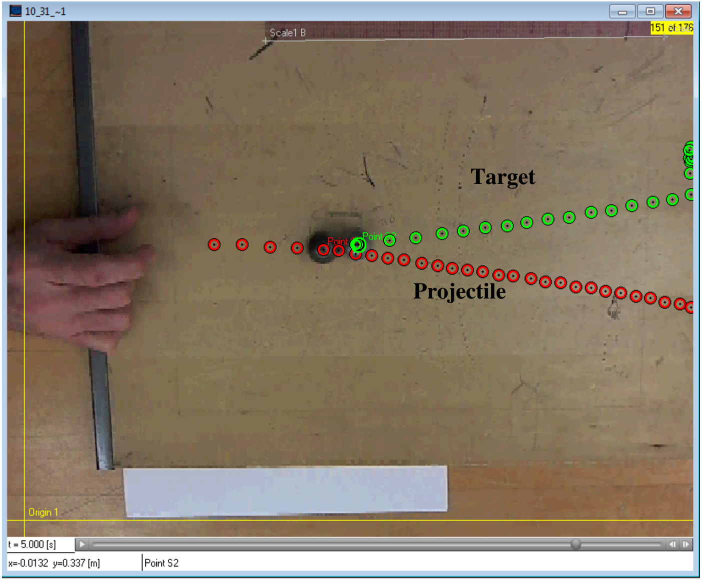
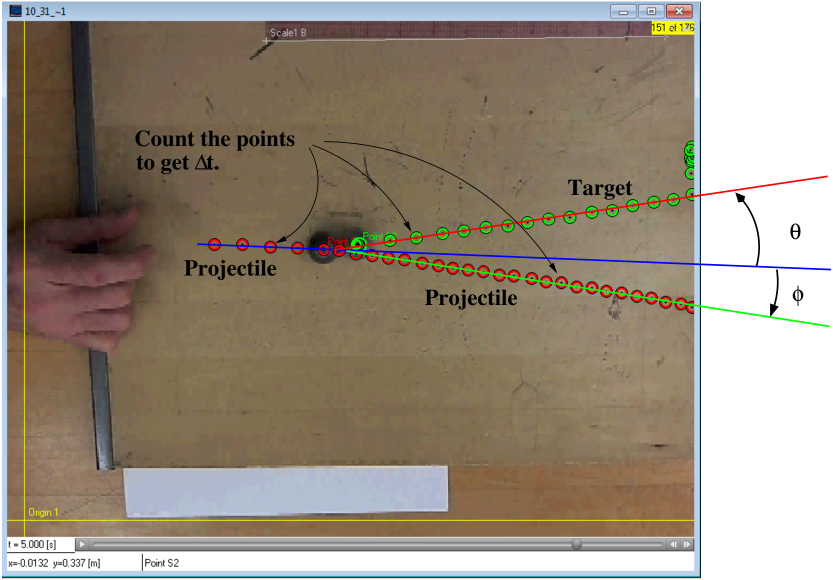
B -6.362E-2
Drag table columns to yellow (horizontal axis) or green (vertical axis) for curve fitting.
non-editable



row	t	x
0	0	-0.001
1	0.032	-0.026
2	0.08	-0.055
3	0.112	-0.083
4	0.144	-0.112
5	0.176	-0.142
6	0.224	-0.162
7	0.256	-0.181
8	0.288	-0.199
9	0.32	-0.214
10	0.368	-0.23
11	0.4	-0.243
12	0.432	-0.26
13	0.464	-0.275
14	0.512	-0.291
15	0.544	-0.309
16	0.576	-0.327
17	0.608	-0.341
18	0.656	-0.358
19	0.688	-0.373
20	0.72	-0.393
21	0.752	-0.405
22	0.8	-0.425
23	0.832	-0.444
24	0.864	-0.456
25	0.896	-0.47
26	0.928	-0.483
27	0.976	-0.505
28	1.008	-0.527
29	1.04	-0.425

Analyzing the collision




10_31_~1
Scale1 B
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Count the points
to get Δt.
Target
Projectile
Projectile
θ
ϕ
Origin 1
t = 5.000 [s]
x=-0.0132 y=0.337 [m]
Point S2