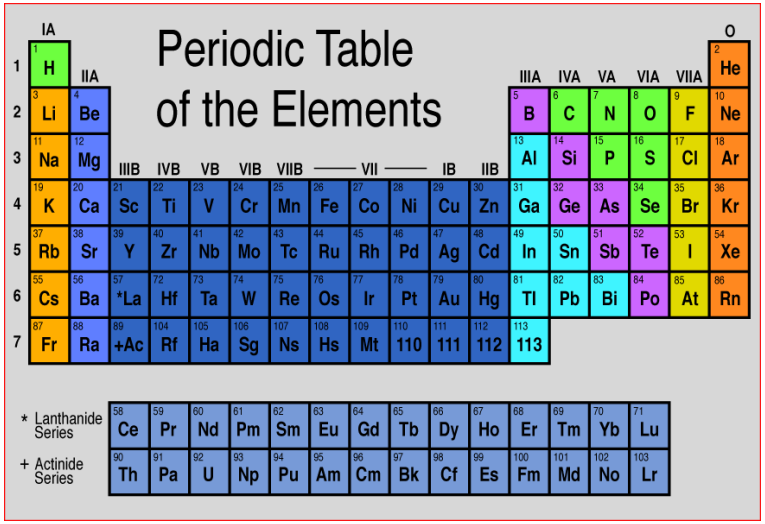
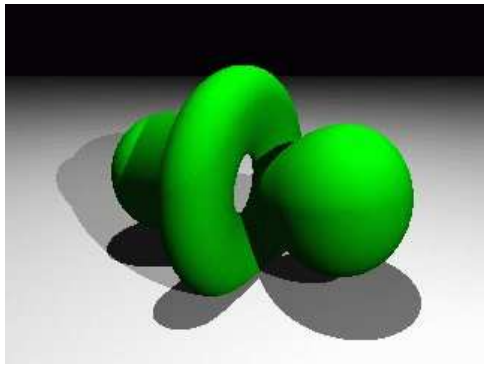
The Quest for Quarks

"The Periodic Table"

The Frontiers of Matter (in 1932)

- The periodic chart orders the chemical elements according to their properties.
- It provides clues to the underlying atomic structure.
- The ‘fundamental particles’ of the periodic chart are the atoms.





hydrogen n=3, l=1, m=0

- What is an element?

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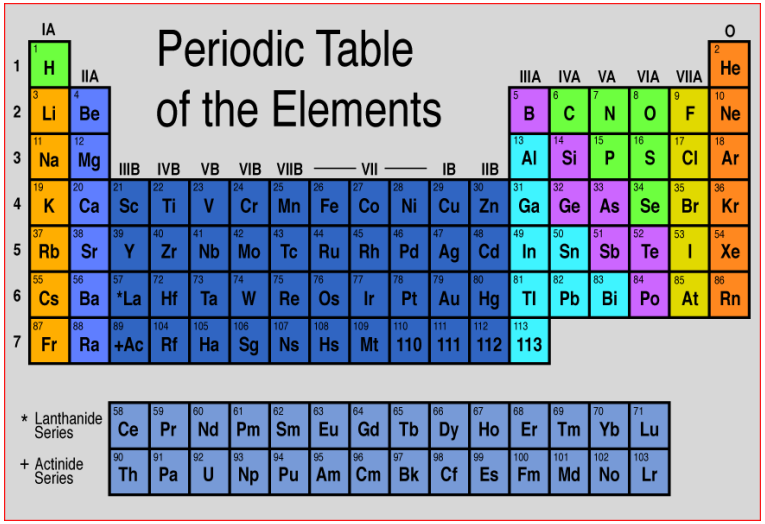

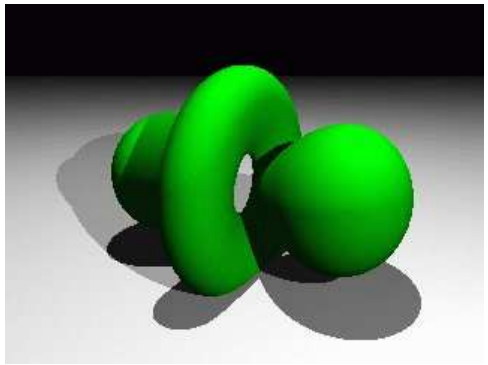

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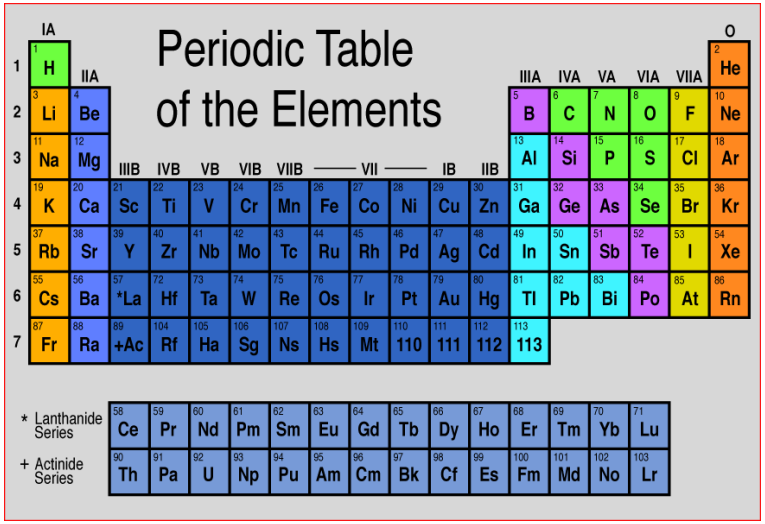

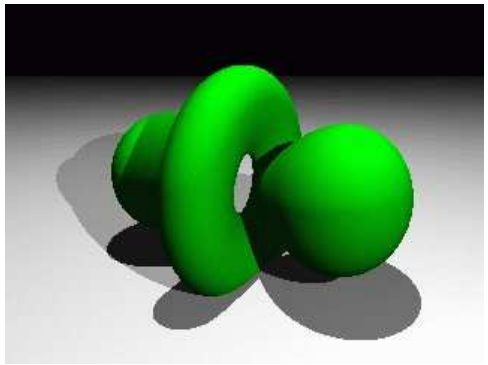

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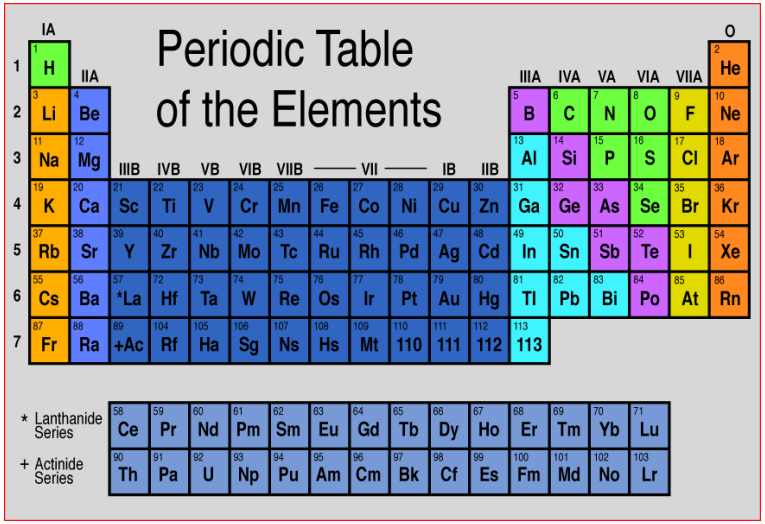

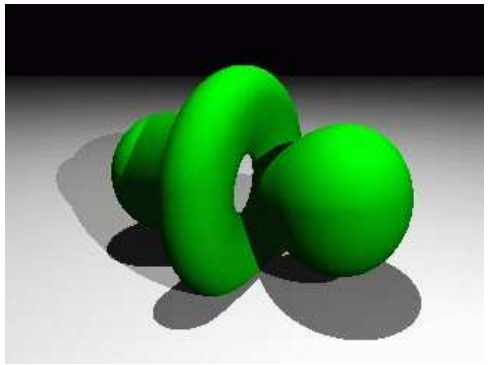

hydrogen n=3, l=1, m=0

- What is an element?
- Webster’s Dictionary: The simplest principles of a subject of study.
- What are the fundamental particles of the elements?
- Protons and neutrons.

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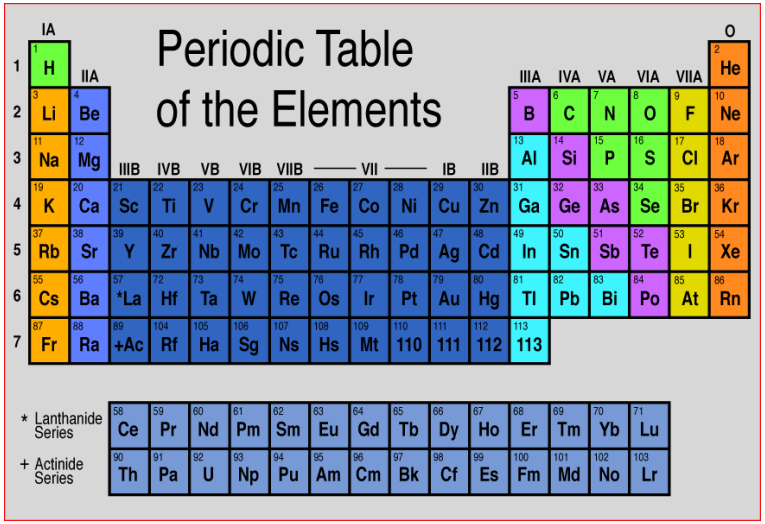

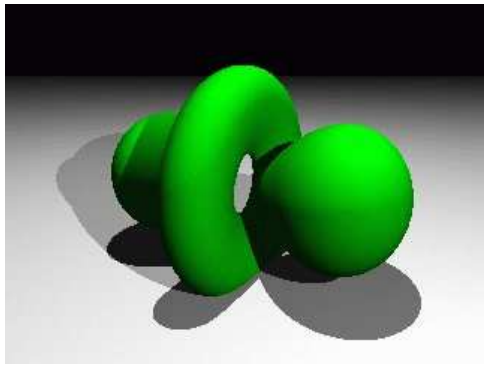

hydrogen n=3, l=1, m=0

- What is an element?
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What is inside the protons and neutrons?

- Protons and neutrons.

The Frontiers of Matter (now)

- The Universe is made of quarks and leptons and the force carriers.

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

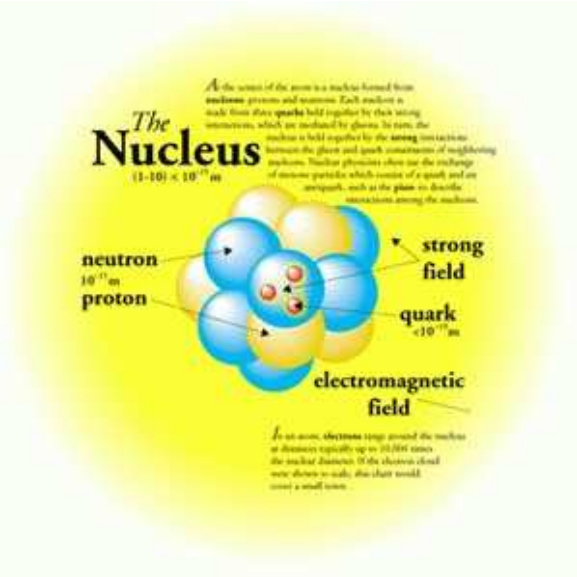
Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0

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

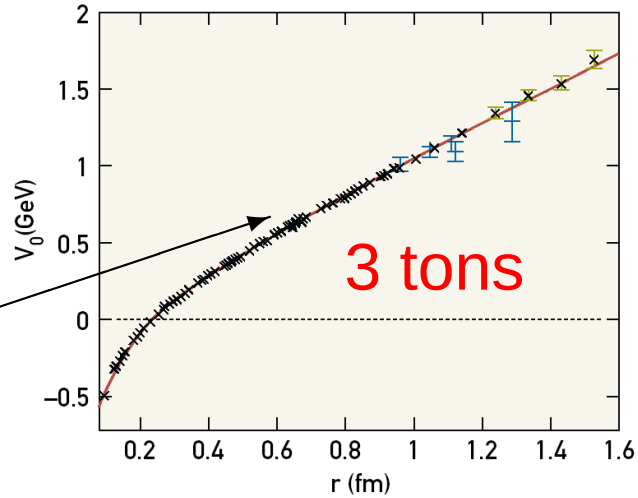
Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

- The atomic nucleus is made of protons and neutrons bound by the strong force.
- The quarks are confined inside the protons and neutrons.
- Protons and neutrons are NOT confined.



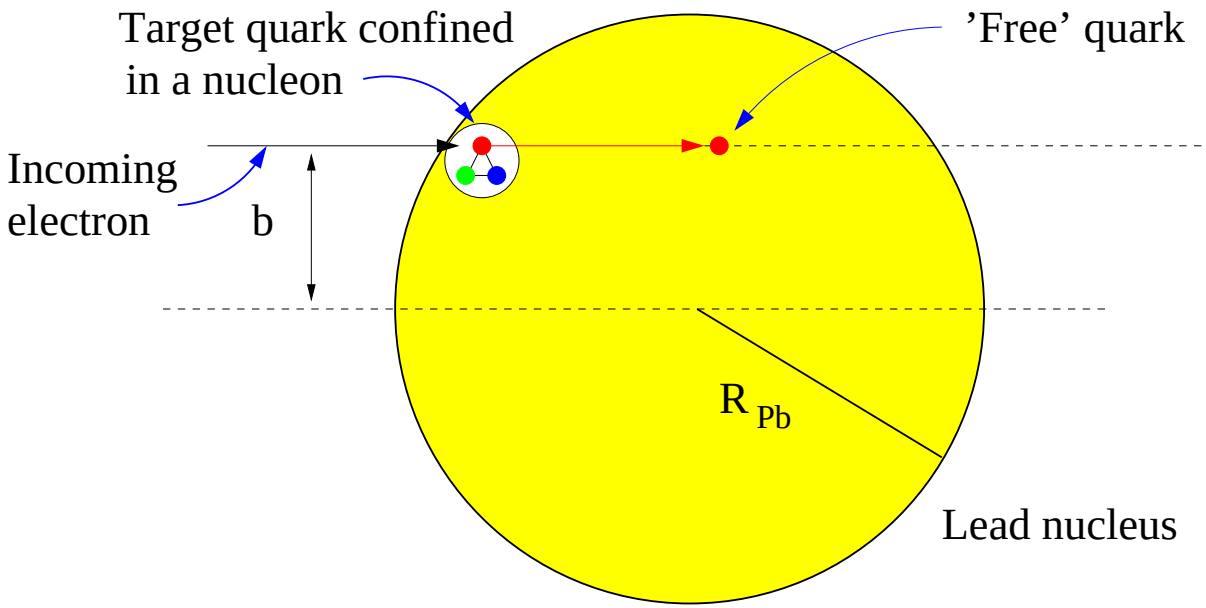
Quark Confinement

- No bare quarks have ever been observed. This is radically different from molecules, atoms, and atomic nuclei which have been picked apart using particle beams, lasers, ...
- This property of the quarks is called CONFINEMENT.
- The leading theory describing the force between quarks is called Quantum Chromodynamics (QCD). The inventors, David J. Gross, H. David Politzer, and Frank Wilczek, received the Nobel Prize in 2004.



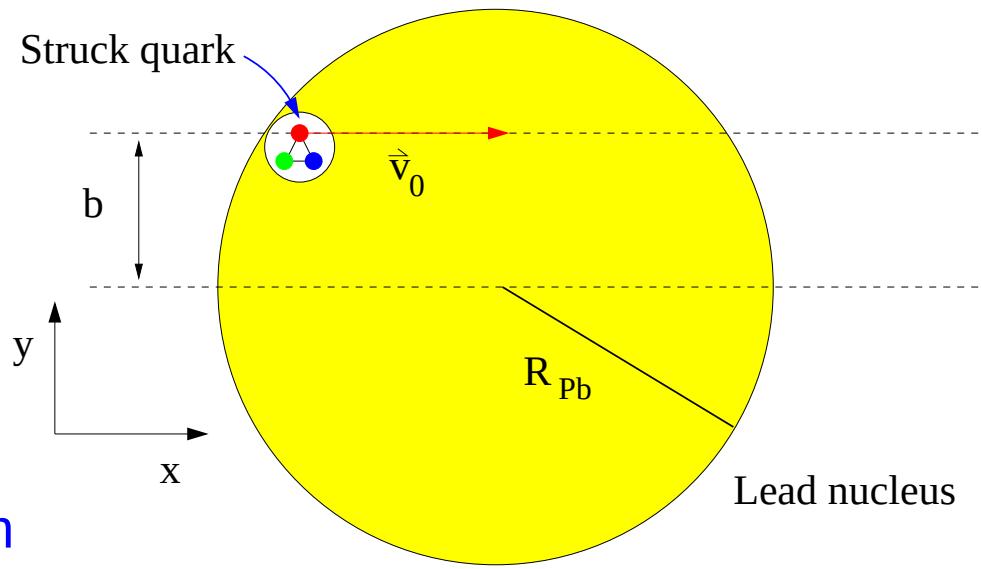
Setting the Quarks Free

Despite quark confinement there is a way to get them out of the proton or neutron. Hit a quark hard enough (with something small like an electron) and if it is immersed in nuclear matter, the tug of the nearby nucleons (protons and neutrons) partly balances the quark force. We'll treat this struck quark as a particle moving through the nucleus bound to it original partners by a string that exerts a constant force.



Does the quark escape?

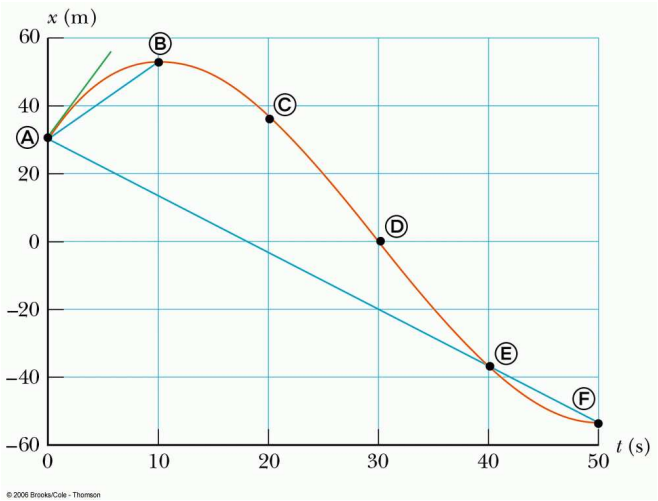
An electron strikes the quark bound inside a nucleon that is a constituent of a lead nucleus in the configuration shown in the figure. The quark is near the surface of the nucleus. The collision gives the quark an initial velocity of $\vec{v}_o = 3 \times 10^8\ m/s\ \hat{i}$. The net acceleration on the struck quark as it moves through the nuclear medium is $\vec{a} = -4 \times 10^{30}\ m/s^2 \hat{i}$. The impact parameter shown in the figure is $b = 3.0 \times 10^{-15}\ m$ or $b = 3.0\ fm$ ($1\ fm = 10^{-15}\ m$) and $R_{Pb} = 7.1\ fm$.

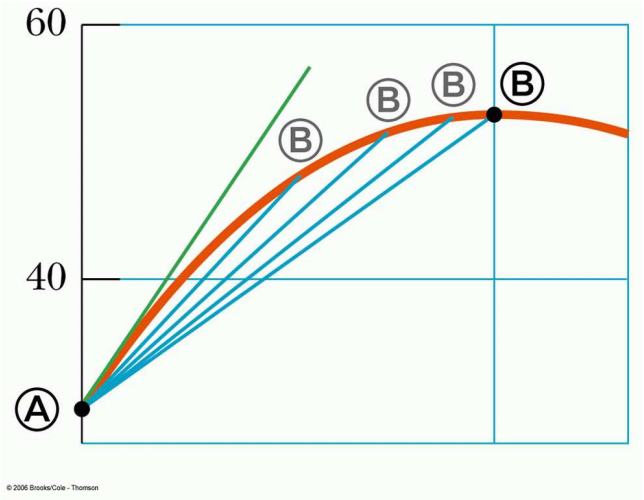


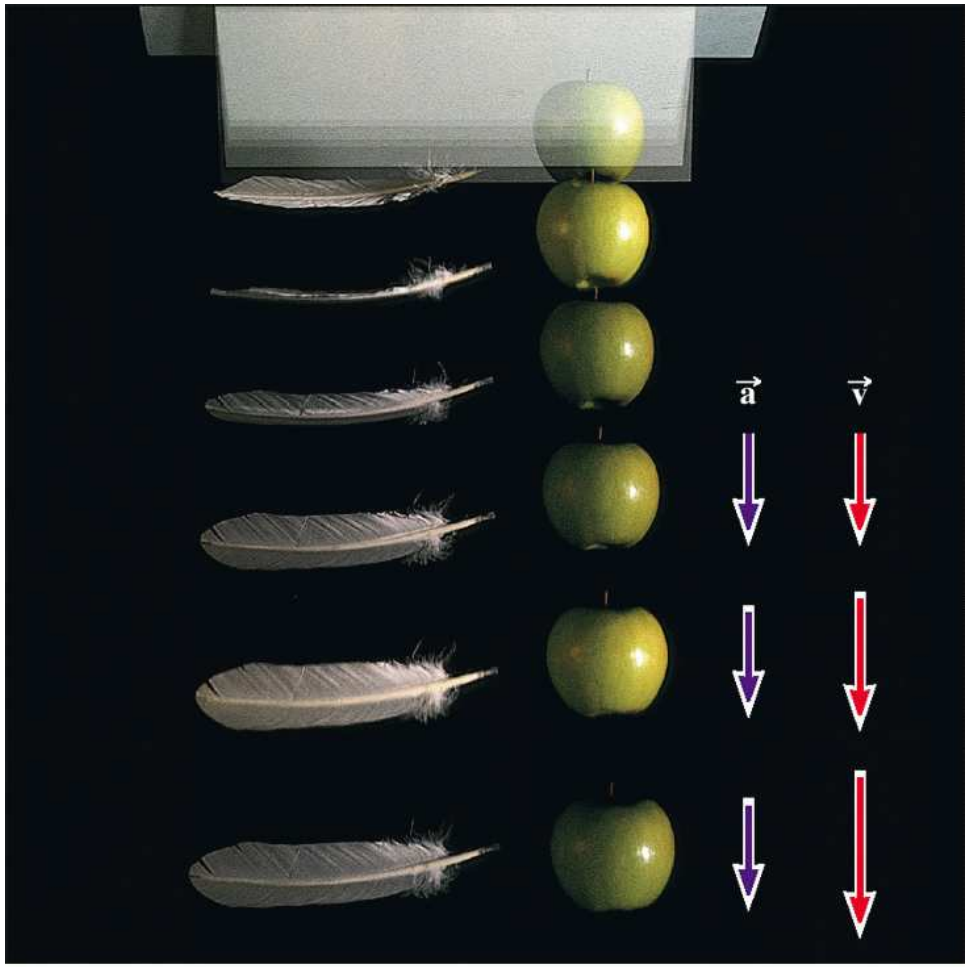
Does the quark make it out of the nucleus?

If the quark travels more than 1 fm the string will break or fragment and new particles will be created. Does the string fragment?

One-Dimensional Motion







One-Dimensional Motion

An elevator in the world's tallest building, the Burj Dubai in Dubai, United Arab Emirates, is moving and its vertical position is described by the following equation

$$y(t) = A + Bt + Ct^2$$

where $A = 5.0\ m$, $B = 2.1\ m/s$, and $C = -4.9\ m/s^2$. What is the instantaneous velocity at any time t? What is the average velocity between two times $t_0 = 0.0\ s$ and $t_1 = 1.0\ s$?

Captain Kirk's Bad Day

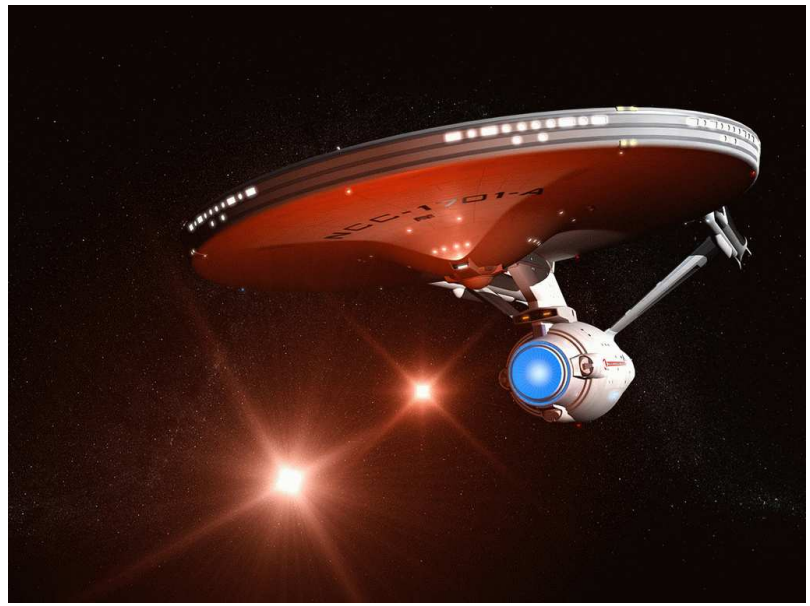
The starship Enterprise has lost power and is plunging straight into the heart of a black hole. Its velocity as a function of time is described by

$$v(t) = F + Gt$$

where $F = 2.0 \times 10^7\ m/s$ and $G = 9.0 \times 10^{10}\ m/s^2$.

What is the average acceleration between $t_1 = 1.0\ s$ and $t_2 = 2.0\ s$?

What is the instantaneous acceleration?

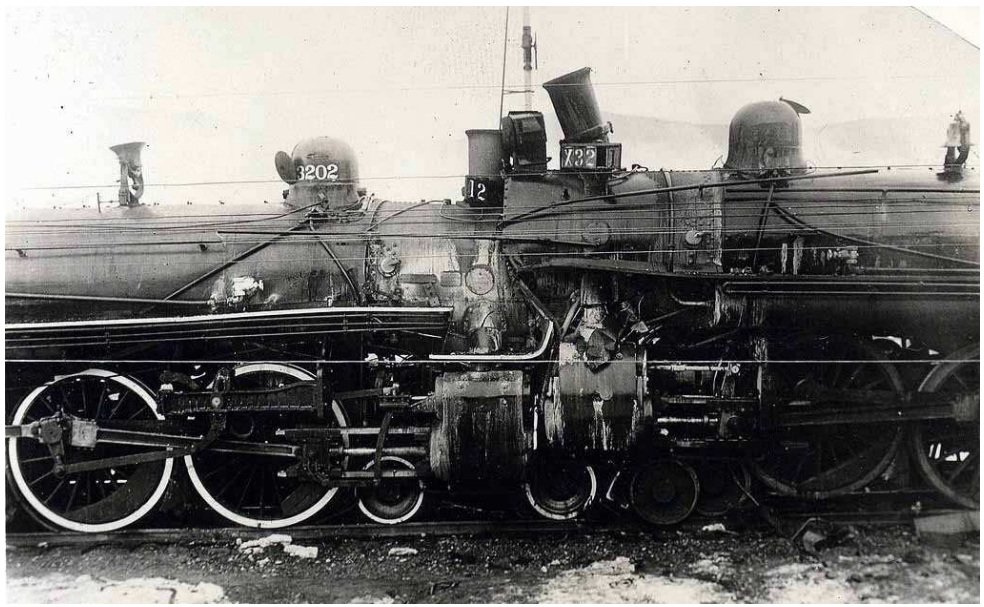


Catching Up

At the instant a traffic light turns green, an automobile starts with a constant acceleration $a = 2.2\ m/s^2$. At the same instant a truck, traveling with a constant speed $v_t = 9.5\ m/s$, overtakes and passes the car. How far does the car travel before overtaking the truck? How fast will the car be moving at that time?

EEEEKKK!!

Two trains, one traveling at $20\ m/s$ and the other at $40\ m/s$, are headed toward one another along a straight, level track. When they are $950\ m$ apart, each engineer sees the other's train and instantly applies the brakes. The slow-moving train stops. The brakes decelerate each train at a rate of $1.0\ m/s^2$. Is there a collision? If so, how long after the brakes are applied?



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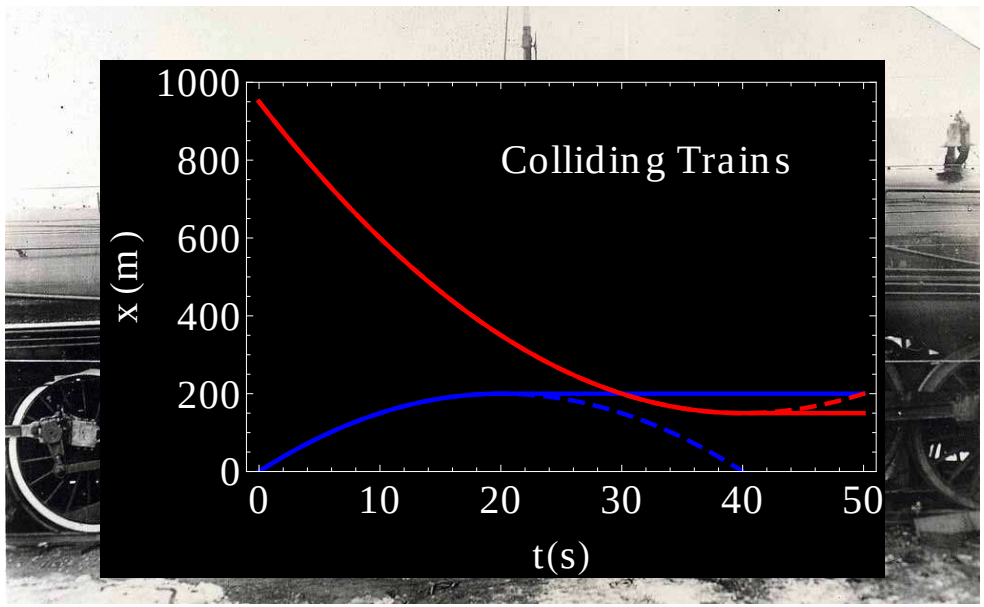
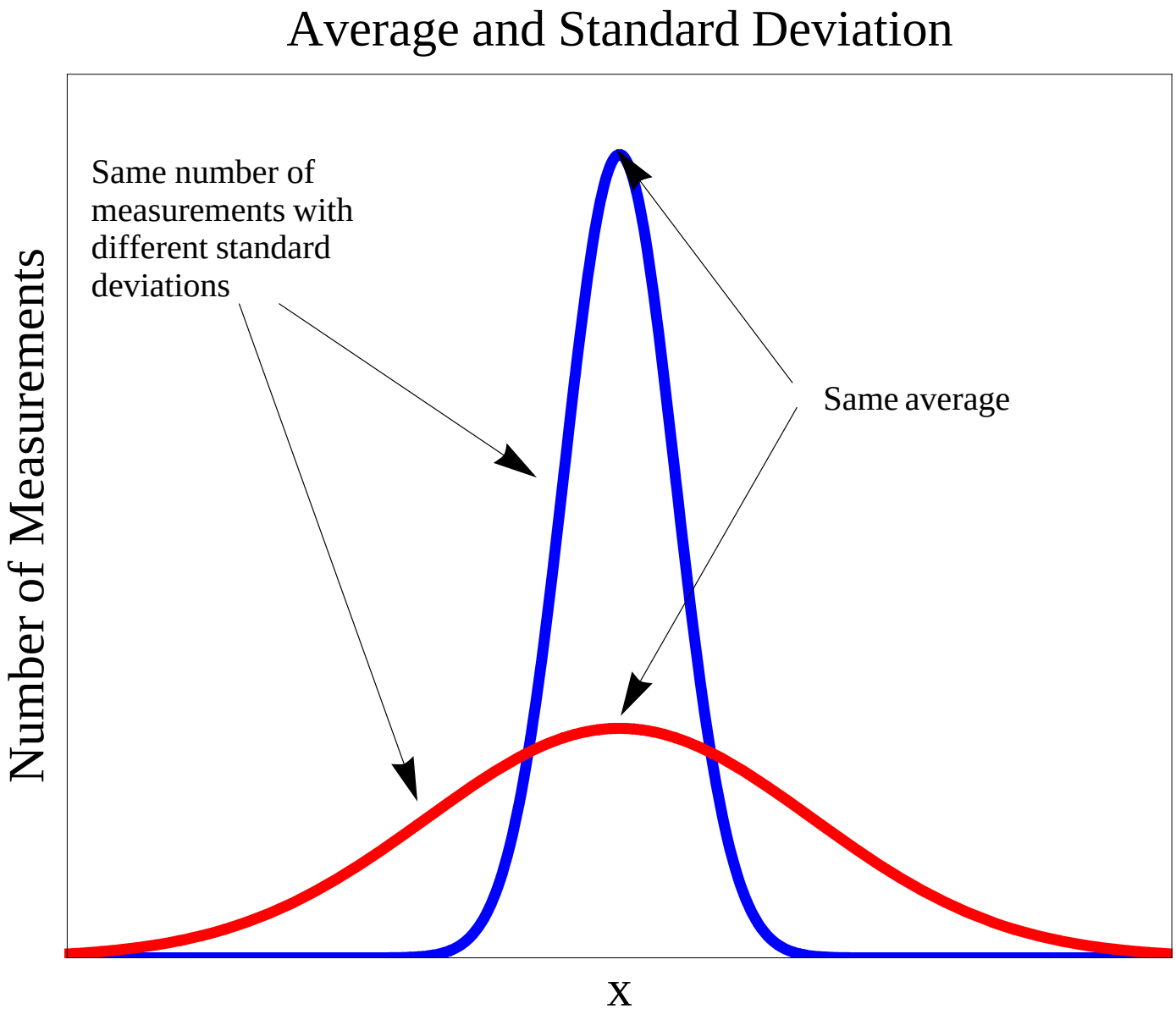


Don’t Do This At Home

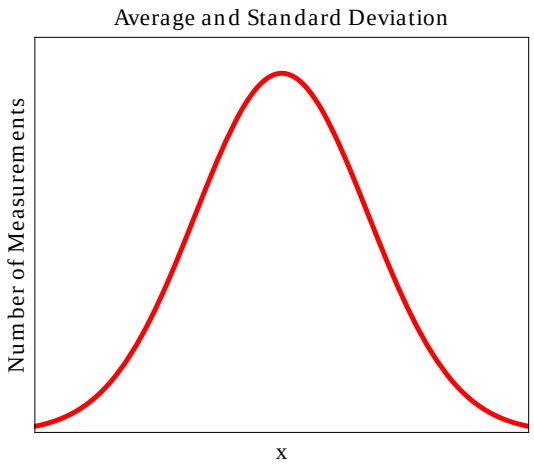
A woman is reported to have fallen (starting from rest) 144 ft or 44 meters from a building and landed on a metal ventilator box and lived. She crushed the ventilator box; compressing it by $0.46\ m$. Ignoring air resistance what is her speed just before colliding with the ventilator box? Treating her acceleration as constant, how long did it take her to come to a stop after she made contact with the box?

Measurement and Uncertainty

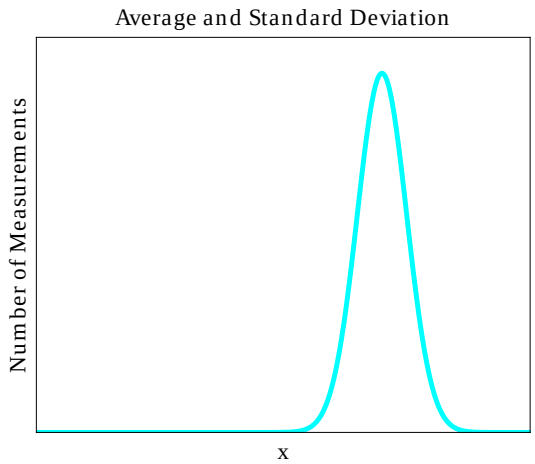


Precision versus Accuracy

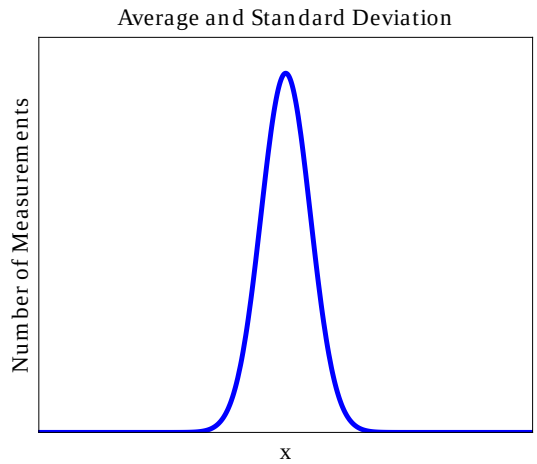
Not precise.



Precise, but not accurate.



Precise and accurate.



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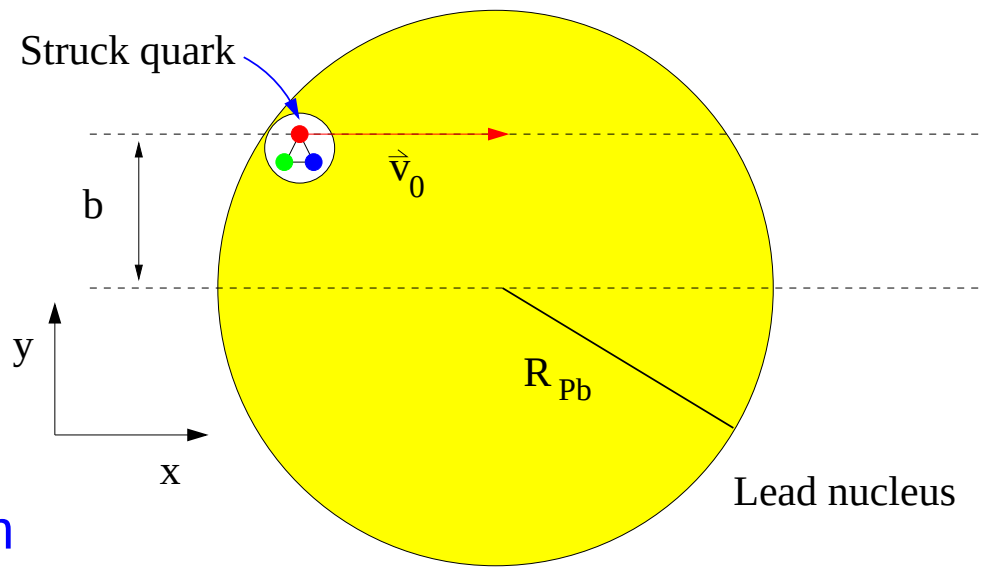

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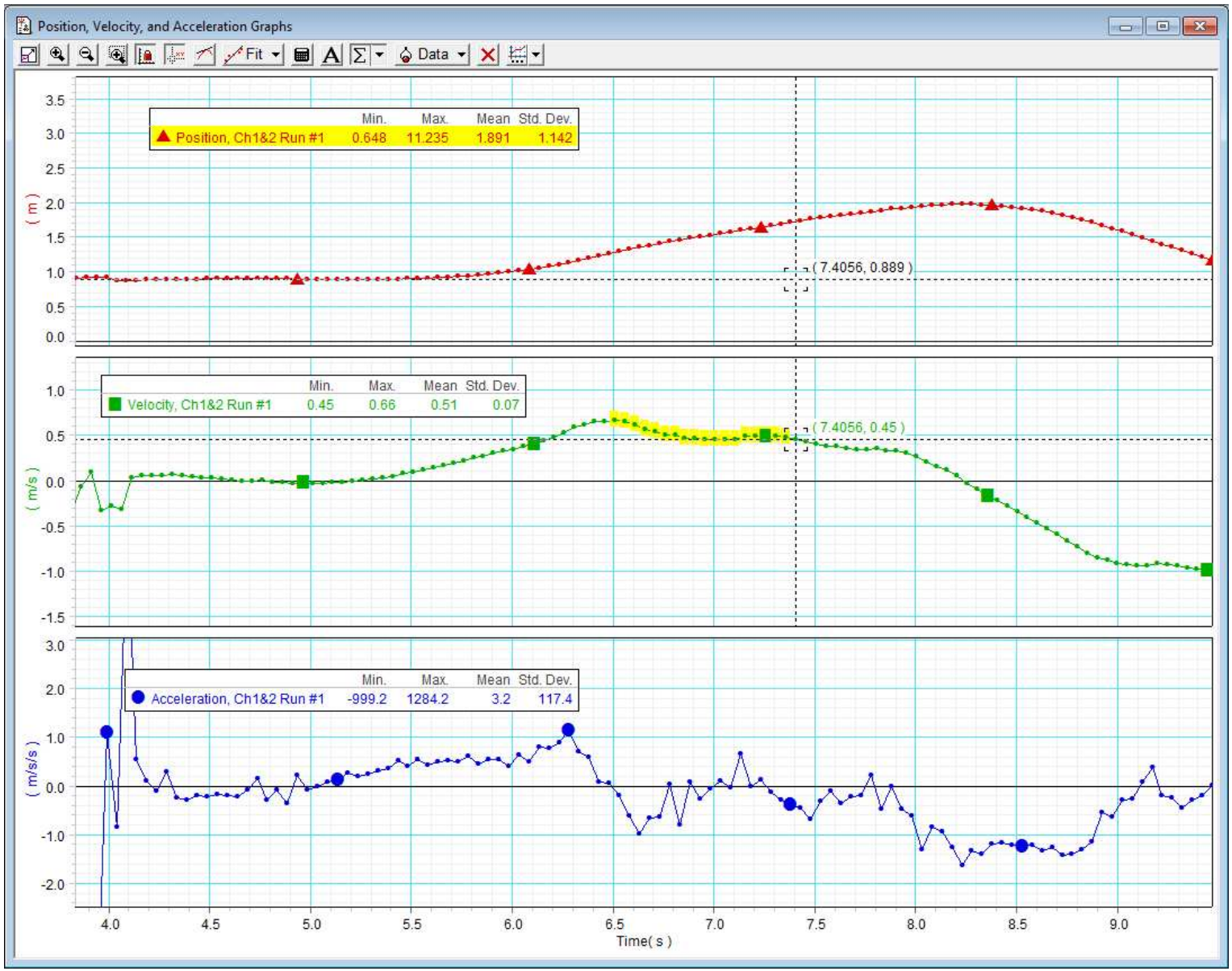
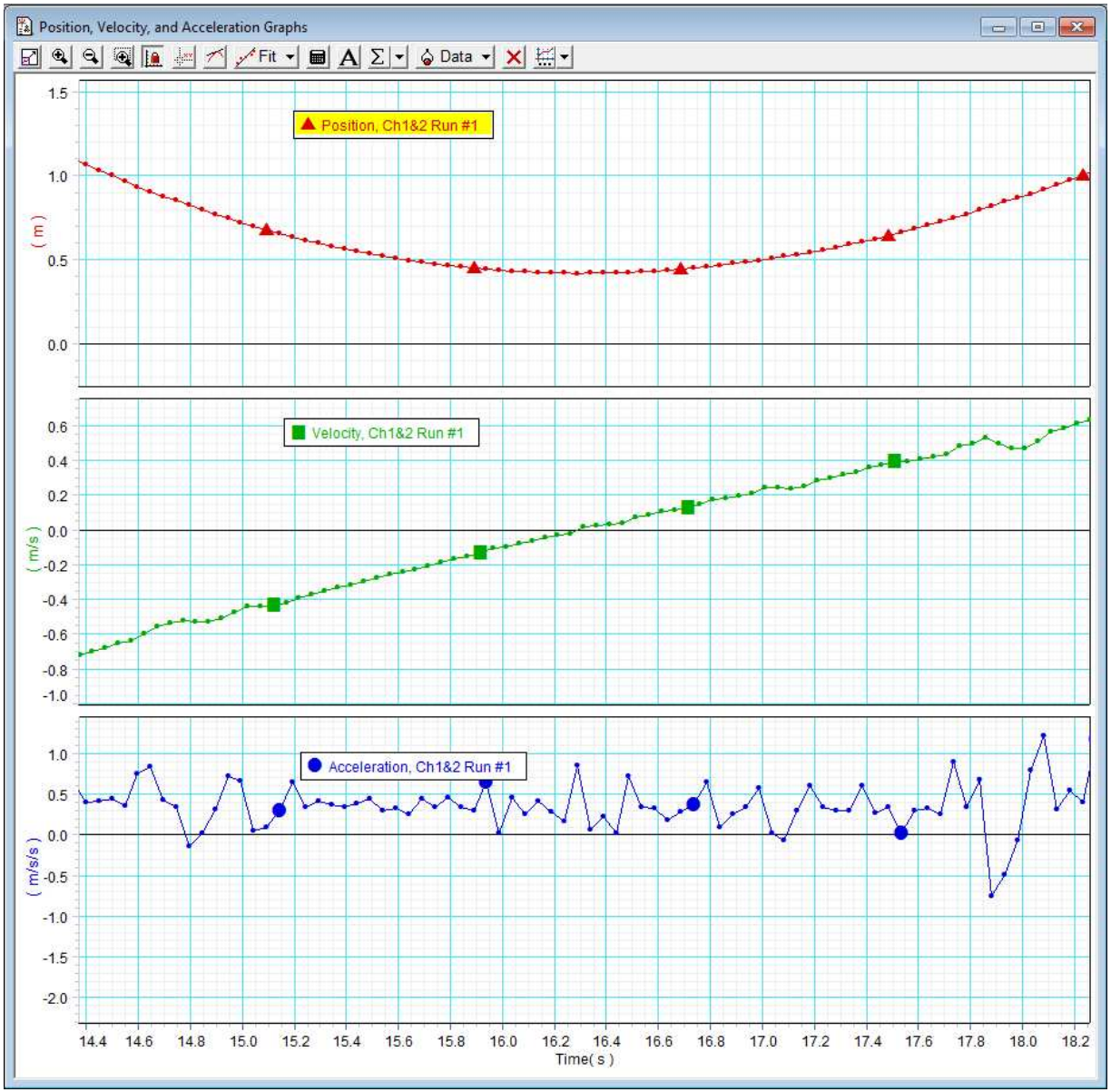
Position and Velocity

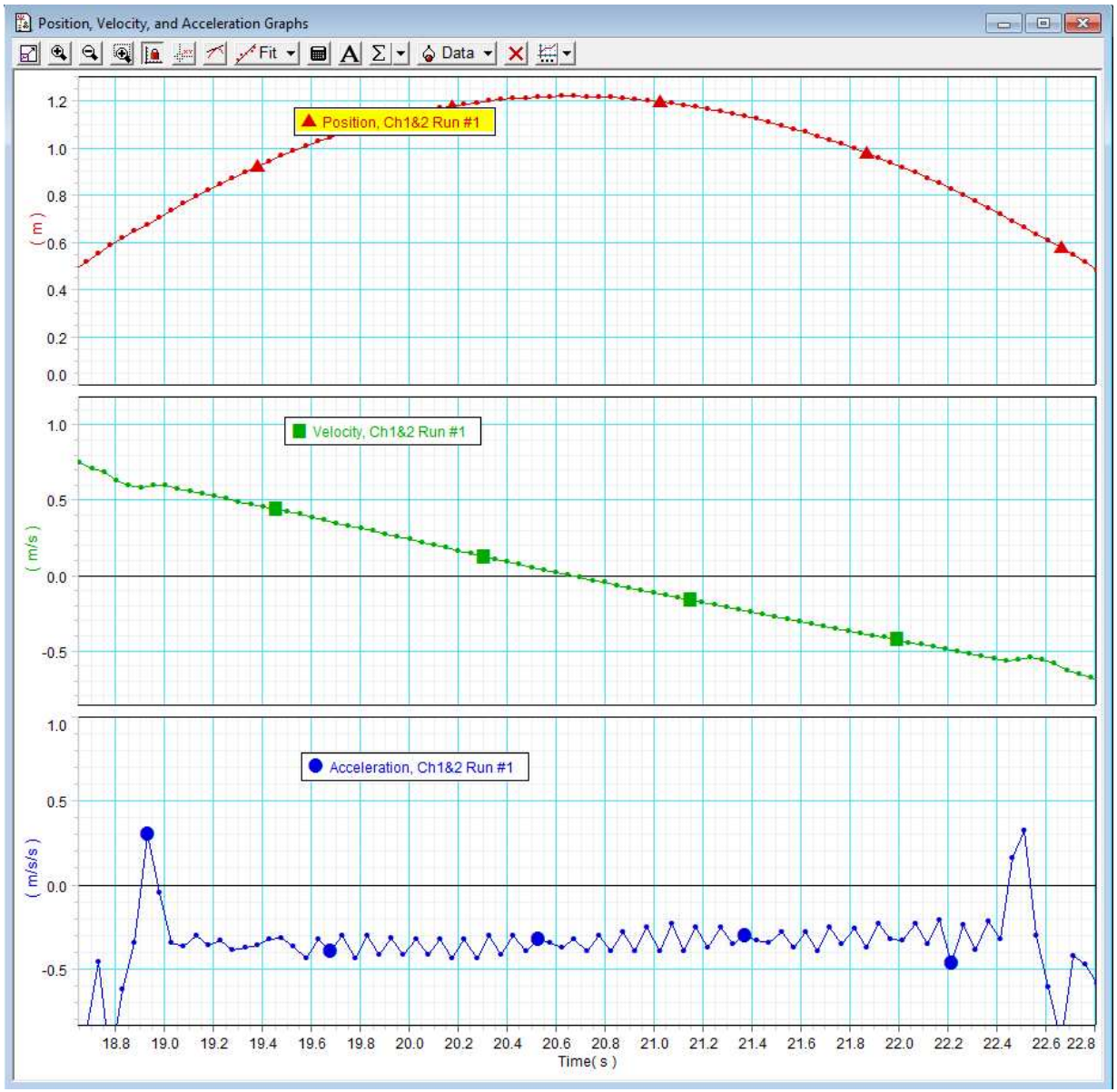
Changing Motion



Turning Around 1

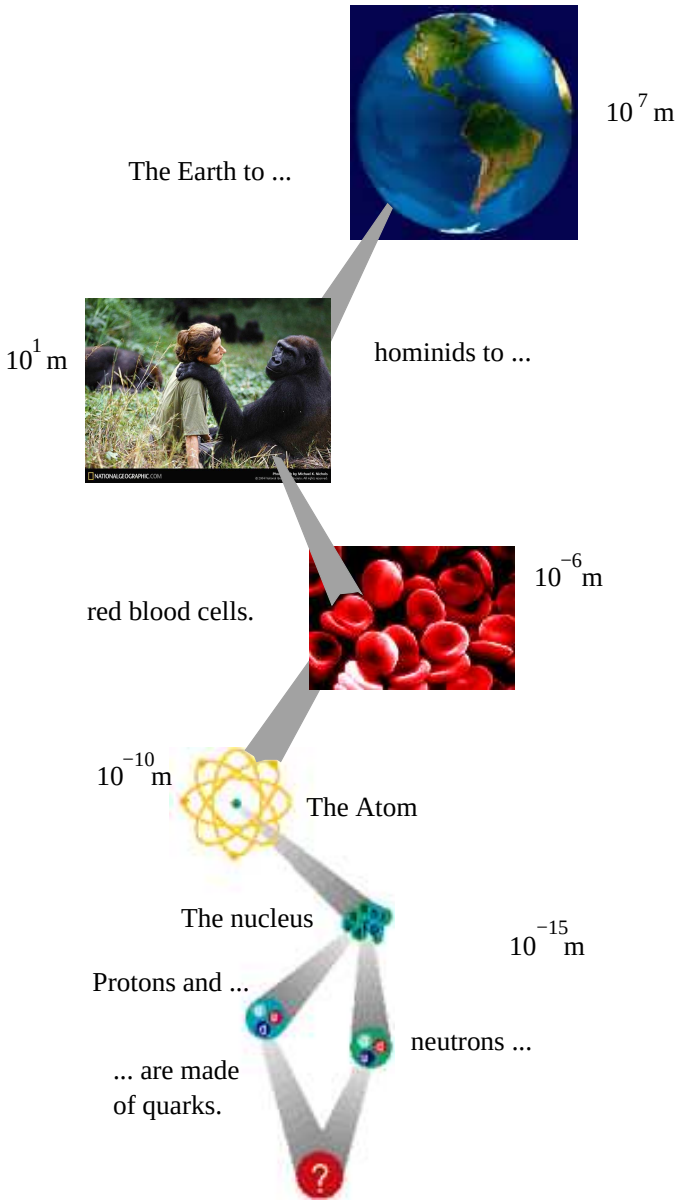


Turning Around 2



Additional Slides

The Quest for Quarks



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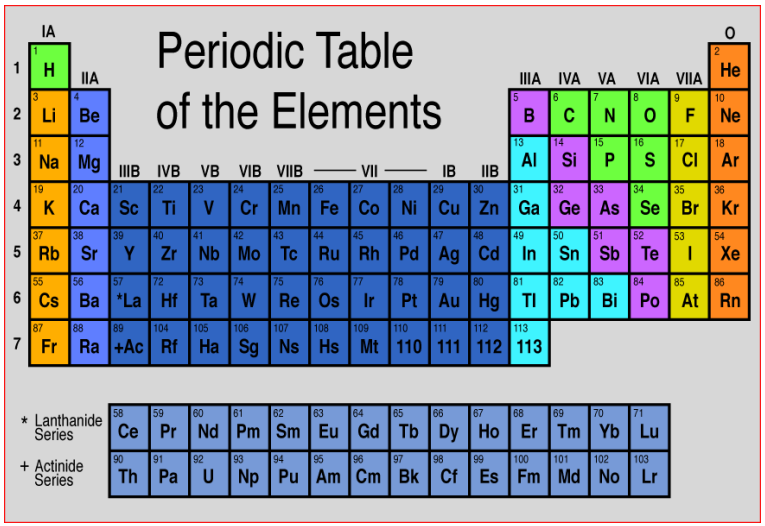
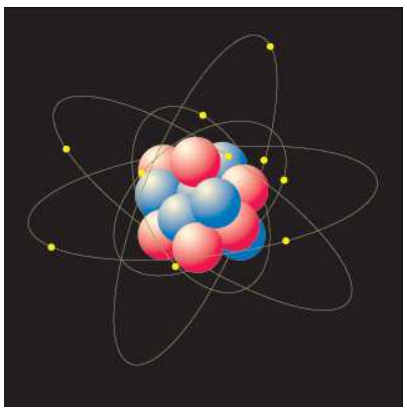
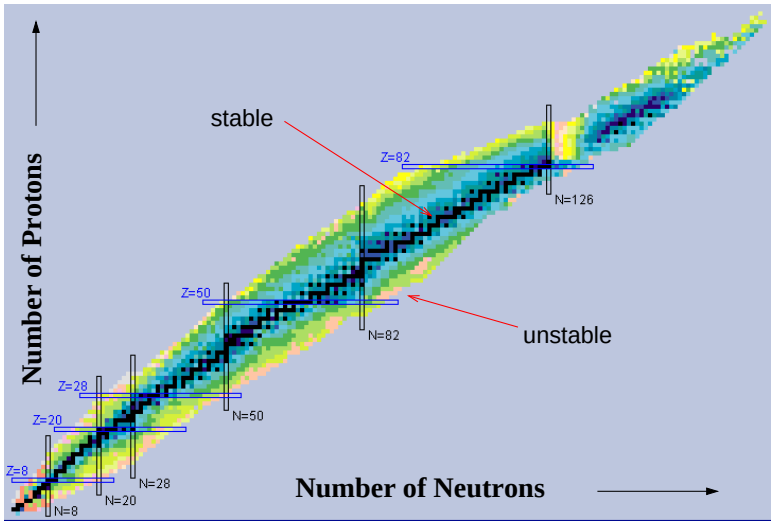




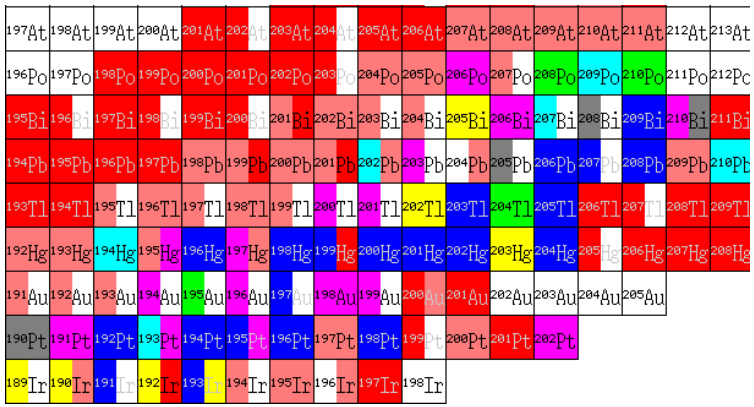
- Atoms have their own fundamental particles: the electron and the nucleus.
- By 1932 we knew the nucleus consisted of protons and neutrons.

The Frontiers of Matter (Nuclei)



- The table of the nuclides orders the atomic nuclei according to their properties.
- It provides clues to the underlying nucleon and quark structure.

- The ‘fundamental particles’ are the proton and neutrons.



On the card:

- Name:
- Email address:
- Class:
- How many semester of physics have you already taken?
- How many semesters of calculus have you already taken?