

The Quest for Quarks



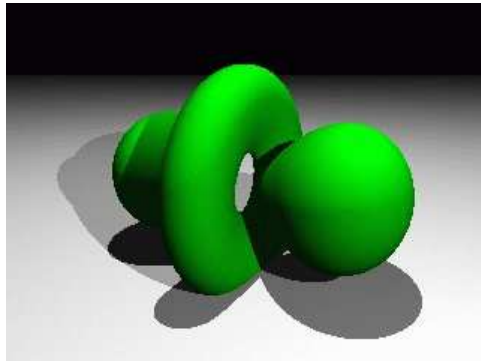
"The Periodic Table"

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.

Periodic Table of the Elements

1																	2		
IA	H																	He	O
3	Li																	10	
2	Be																	Ne	
11	12																	18	
3	Na	Mg																	Ar
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54		
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		
6	Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
87	88	89	104	105	106	107	108	109	110	111	112	113							
7	Fr	Ra	+Ac	Rf	Ha	Sg	Ns	Hs	Mt	110	111	112	113						



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

- What is an element?

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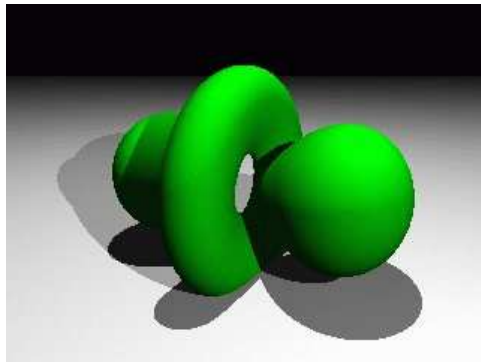
1																	2					
IA																	0					
1	H																	He				
	IIA																					
2	Li	Be															B	C	N	O	F	Ne
																	III A	IV A	V A	VI A	VII A	
3	Na	Mg			III B	IV B	V B	VI B	VII B	VII		IB	II B	Al	Si	P	S	Cl	Ar			
			19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr				
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* Lanthanide Series

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

+ Actinide Series

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



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- What is an element?
- Webster's Dictionary: The simplest principles of a subject of study.

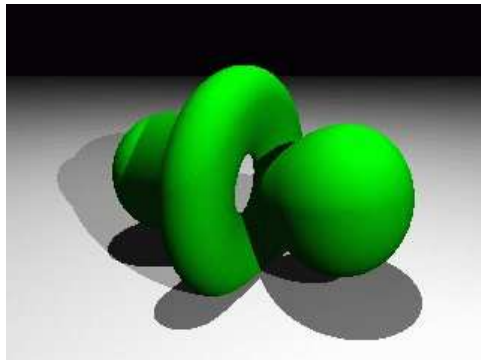
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33	34																	42	43
35	36																	44	45
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39	40																	48	49
41	42																	50	51
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45	46																	54	55
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49	50																	58	59
51	52																	60	61
53	54																	62	63
55	56																	64	65
57	58																	66	67
59	60																	68	69
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67	68																	76	77
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+ Actinide Series



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

- What is an element?
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- What are the fundamental particles of the elements?

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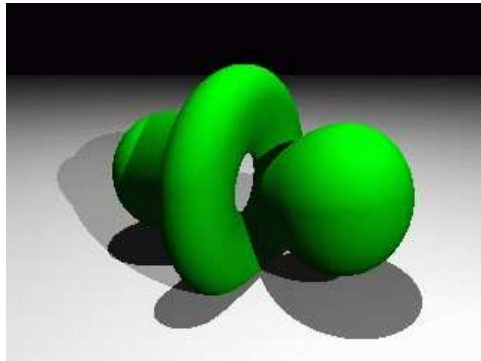
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hydrogen $n=3, l=1, m=0$

- 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.

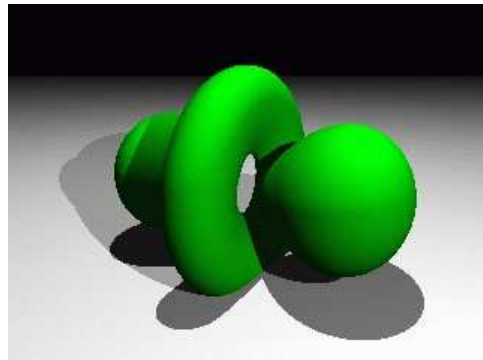
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- What is an element?
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What is inside the protons and neutrons?

- Protons and neutrons.

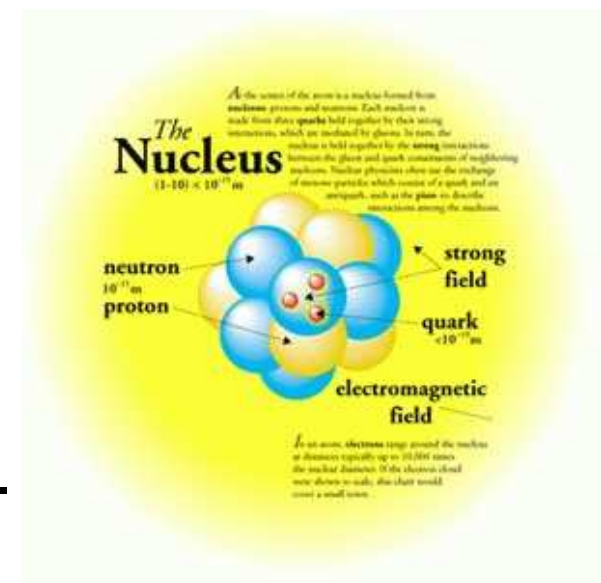
The Frontiers of Matter (now)

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

BOSONS			force carriers spin = 0, 1, 2, ...		
Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge	Name	Mass GeV/c ²	Electric charge
γ photon	0	0	g gluon	0	0
W^-	80.4	-1			
W^+	80.4	+1			
Z^0	91.187	0			

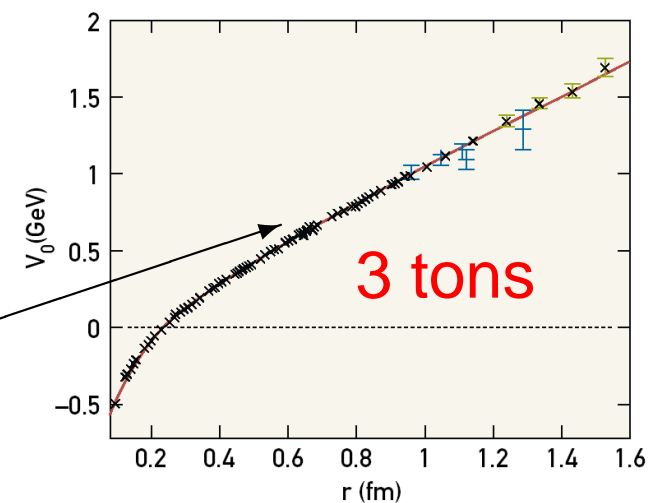
FERMIONS			matter constituents spin = 1/2, 3/2, 5/2, ...		
Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	-1	s strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	-1	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.



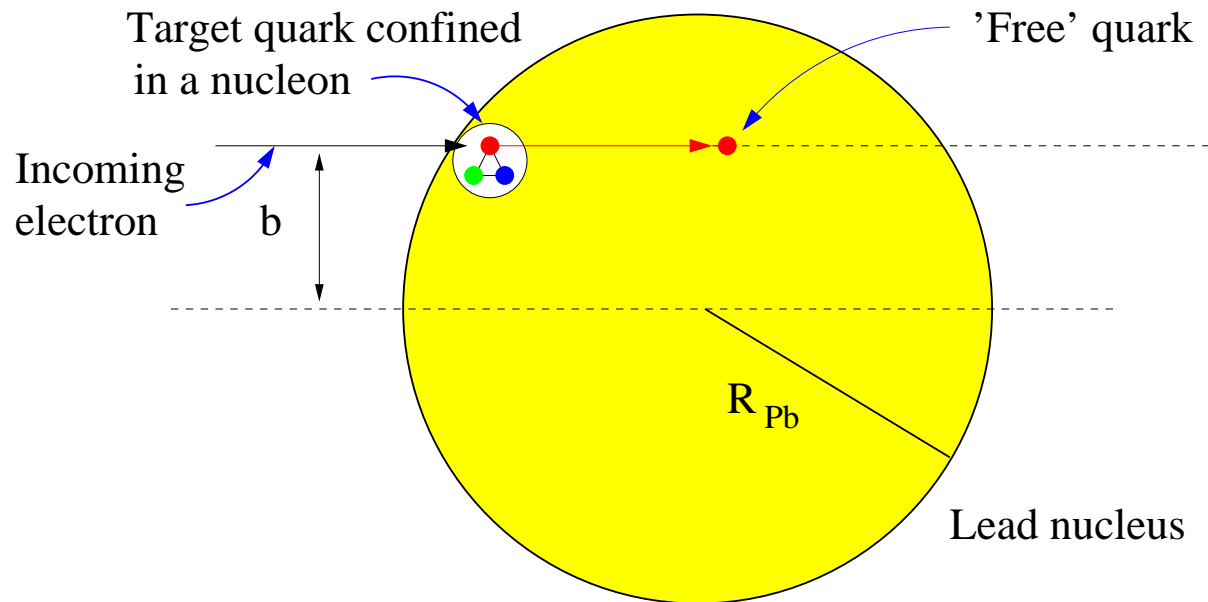
Quark Confinement

- 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.



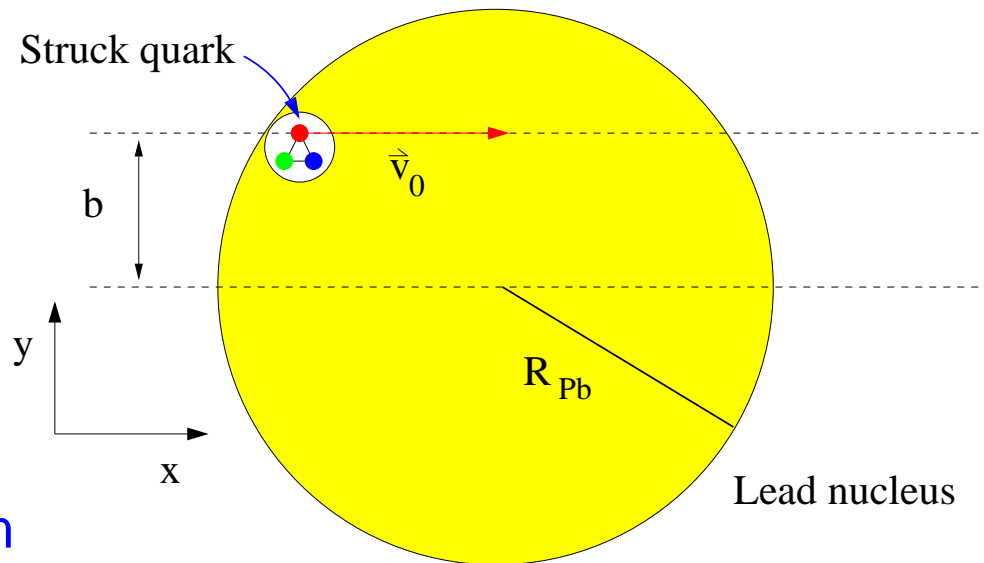
Setting the Quarks Free

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 its original partners by a string that exerts a constant force.



Does the quark escape?

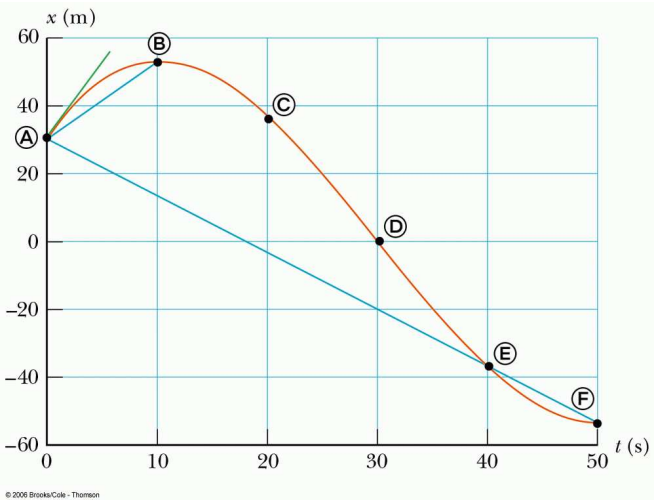
An electron strikes the quark bound inside a nucleon that is a constituent of a lead nucleus in the configuration shown in the figure. The quark is near the surface of the nucleus. The collision gives the quark an initial velocity of $\vec{v}_0 = 3 \times 10^8 \text{ m/s } \hat{i}$. The net acceleration on the struck quark as it moves through the nuclear medium is $\vec{a} = -4 \times 10^{30} \text{ m/s}^2 \hat{i}$. The impact parameter shown in the figure is $b = 3.0 \times 10^{-15} \text{ m}$ or $b = 3.0 \text{ fm}$ ($1 \text{ fm} = 10^{-15} \text{ m}$) and $R_{Pb} = 7.1 \text{ fm}$.



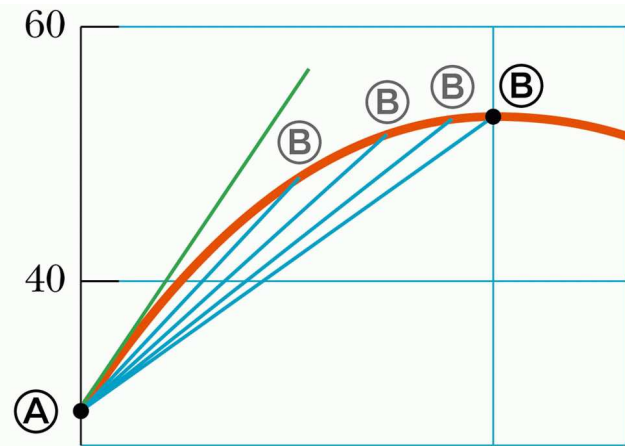
Does the quark make it out of the nucleus?

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

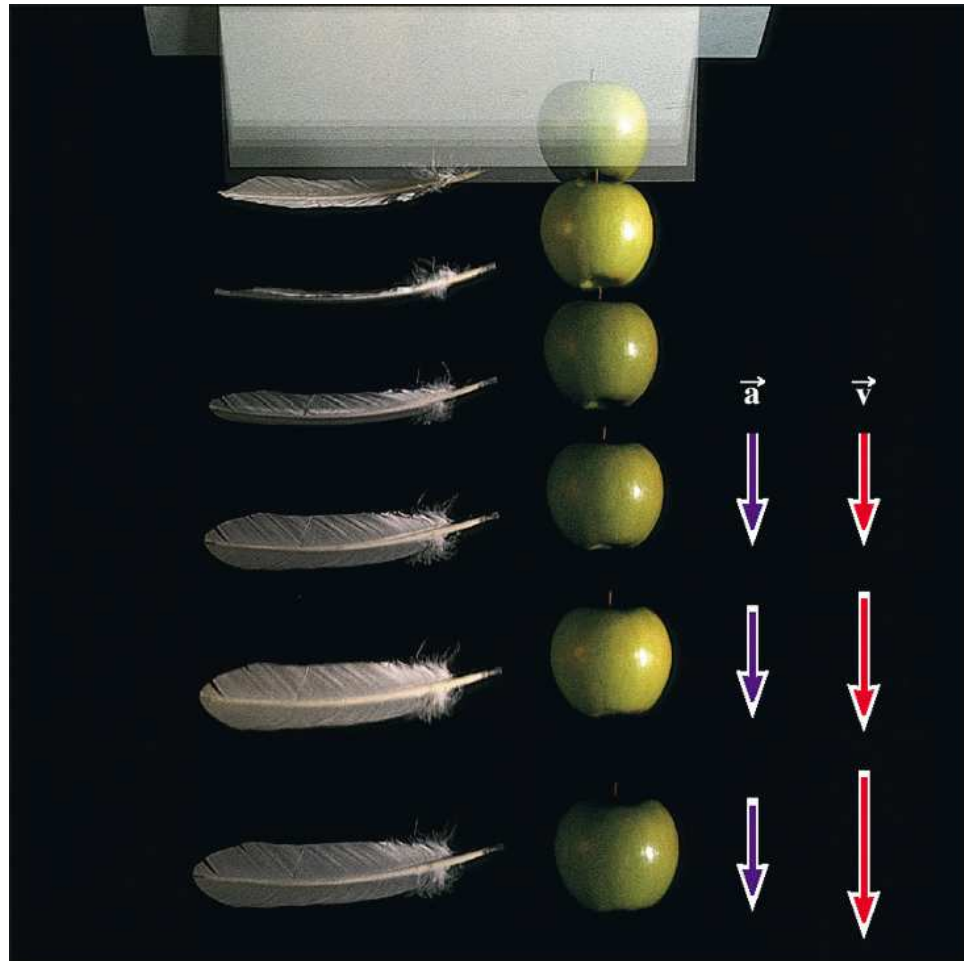
One-Dimensional Motion



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



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

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

What is the instantaneous acceleration?

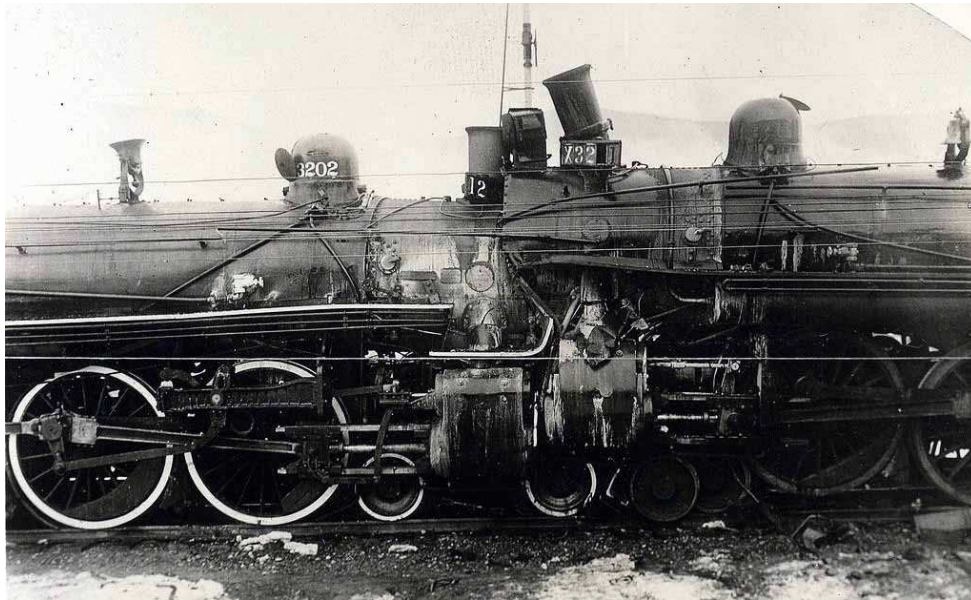


Catching Up

At the instant a traffic light turns green, an automobile starts with a constant acceleration $a = 2.2 \text{ m/s}^2$. At the same instant a truck, traveling with a constant speed $v_t = 9.5 \text{ m/s}$, 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?

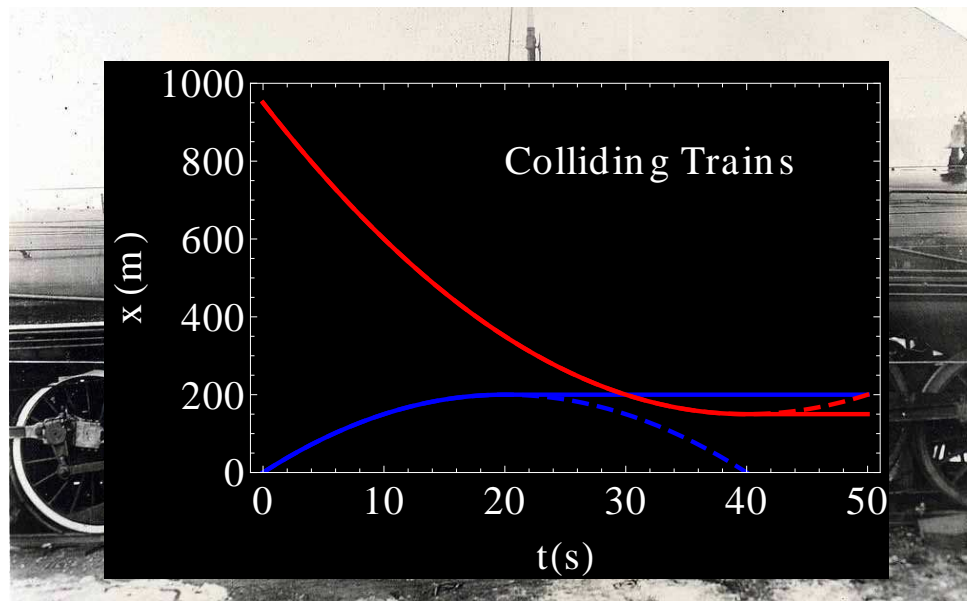
EEEEKKK!!

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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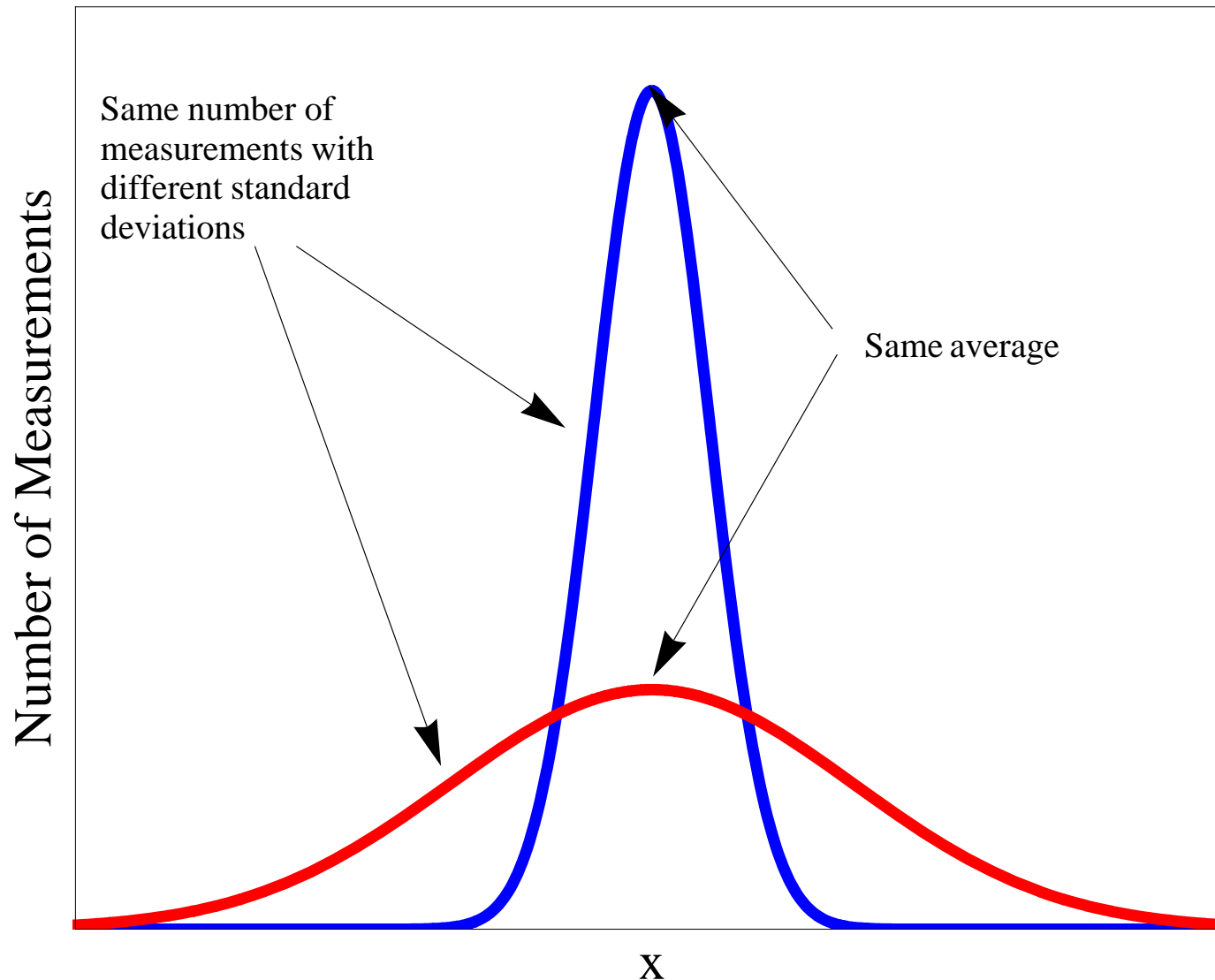


Don't Do This At Home

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

Average and Standard Deviation

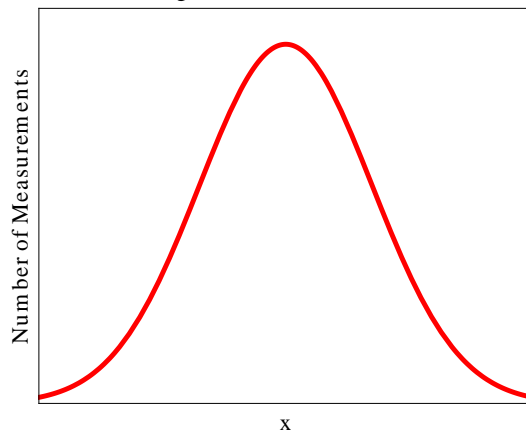


Precision versus Accuracy



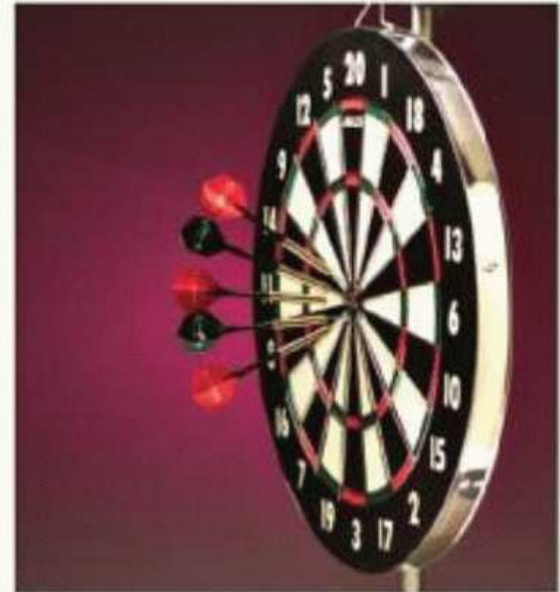
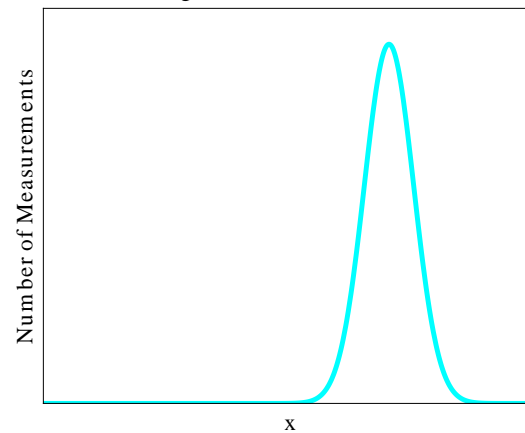
Not precise.

Average and Standard Deviation



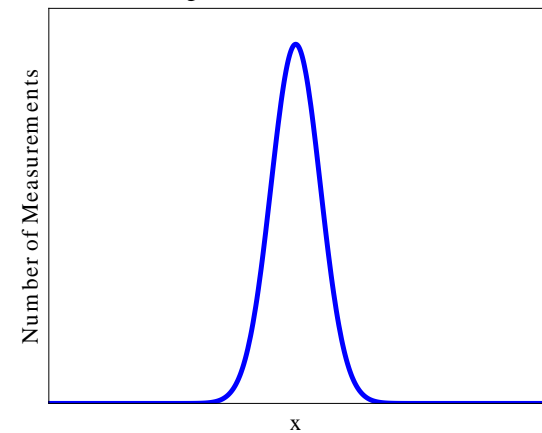
Precise, but not accurate.

Average and Standard Deviation



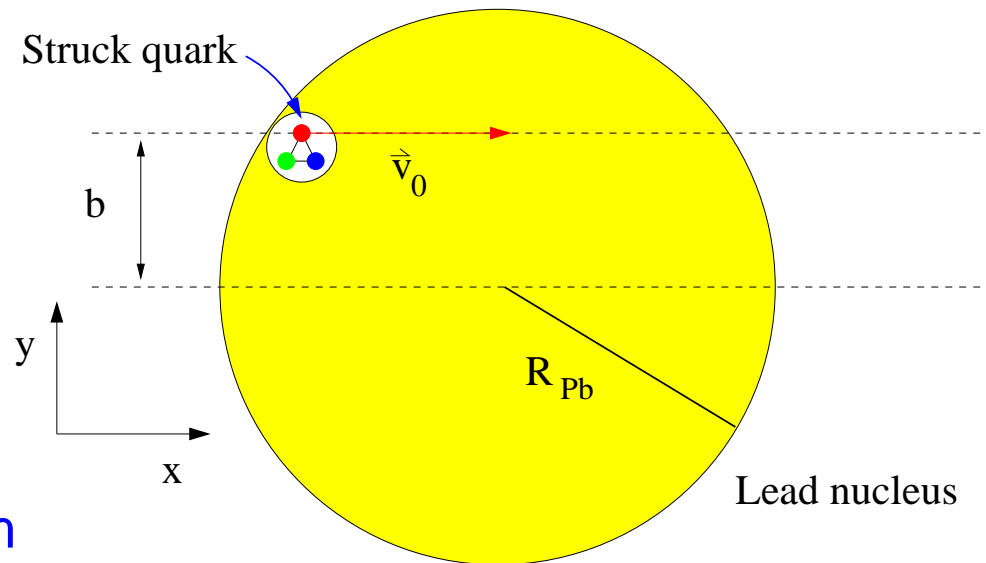
Precise and accurate.

Average and Standard Deviation



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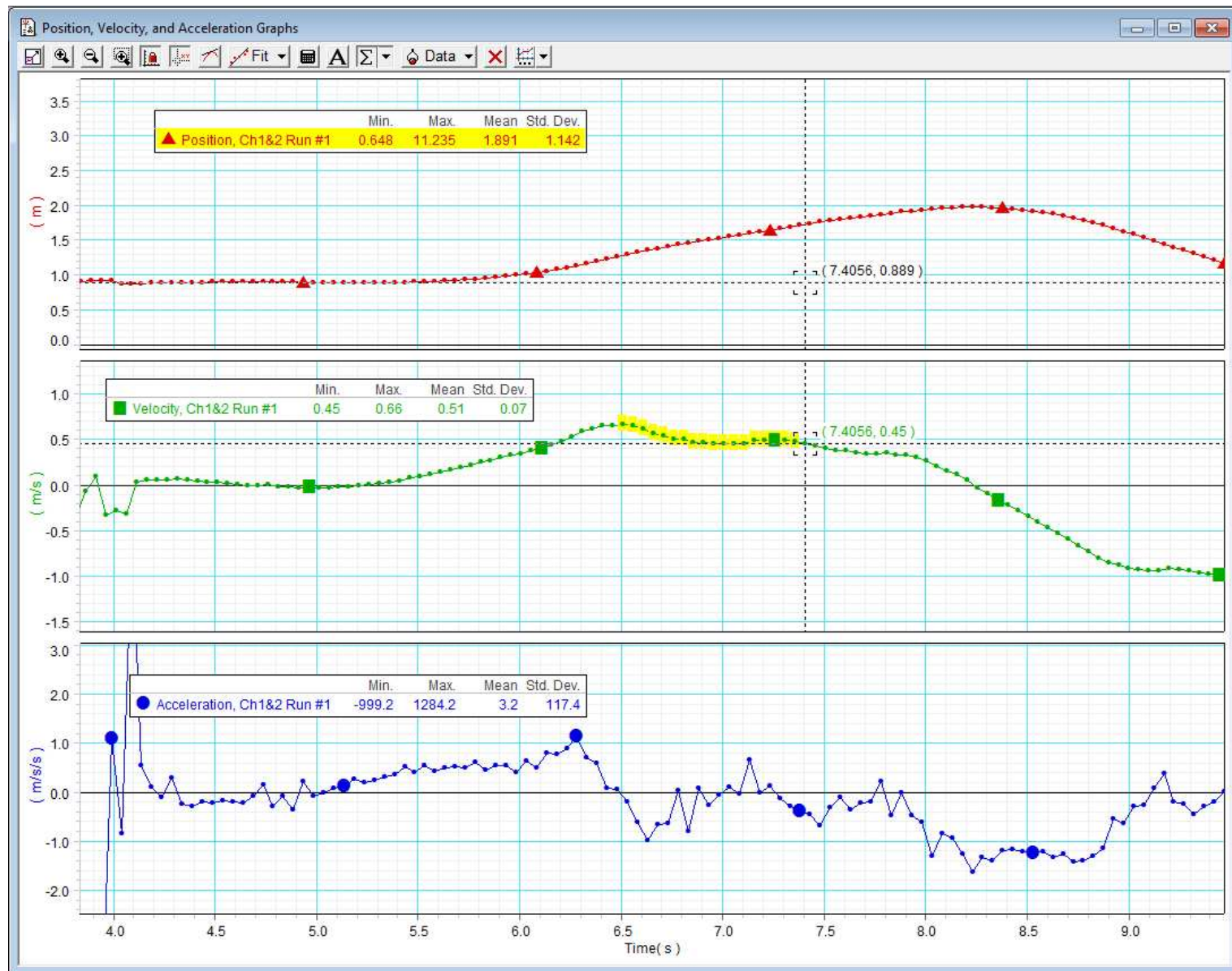
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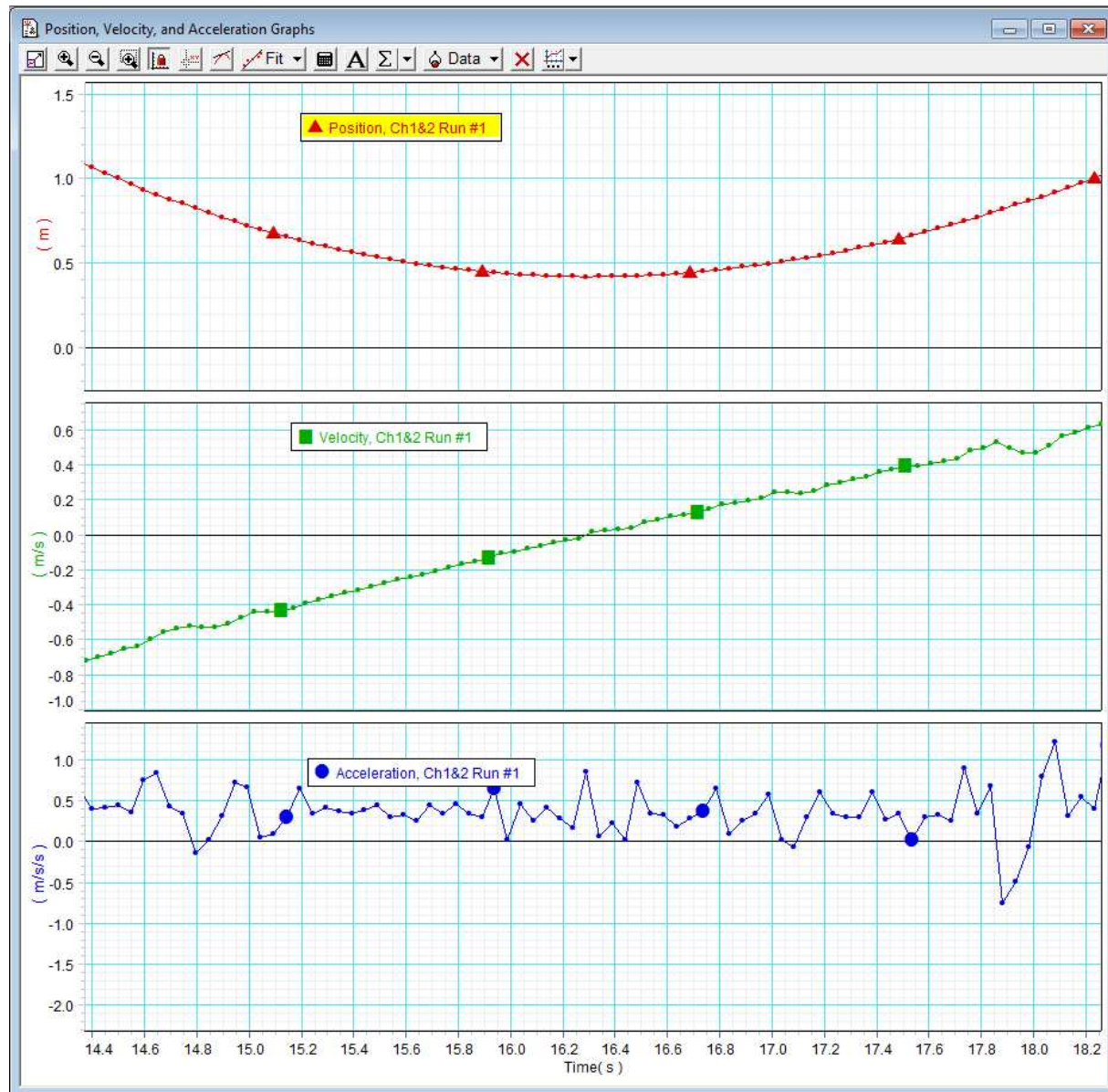
Position and Velocity



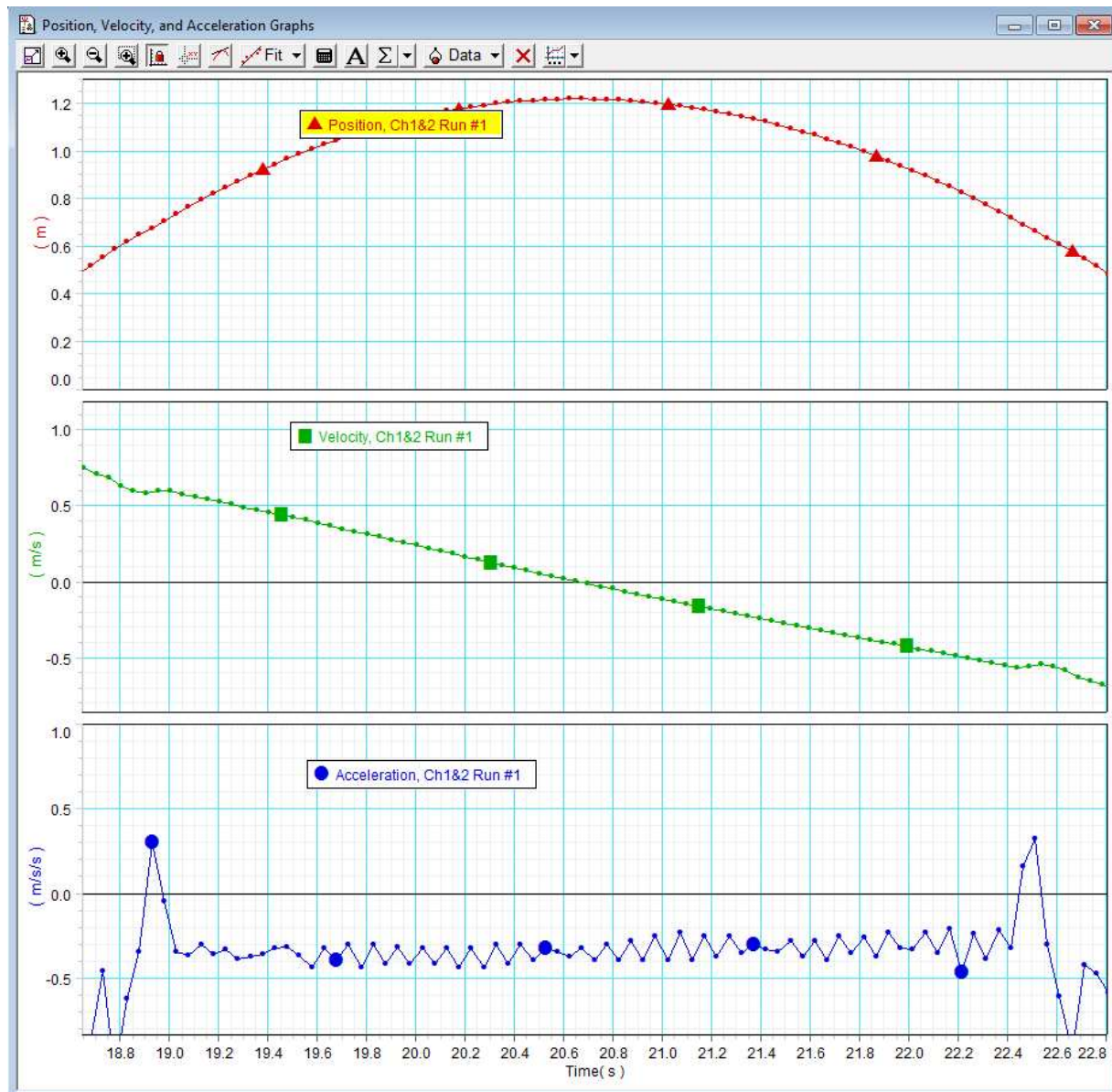
Changing Motion



Turning Around 1

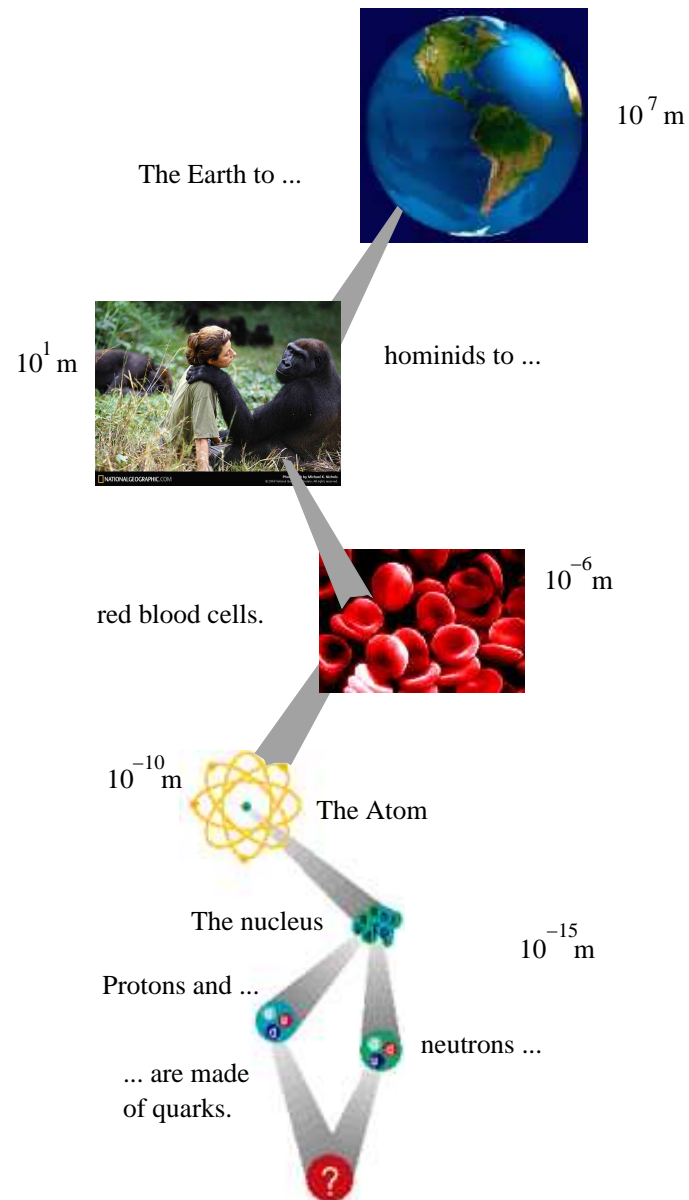


Turning Around 2



Additional Slides

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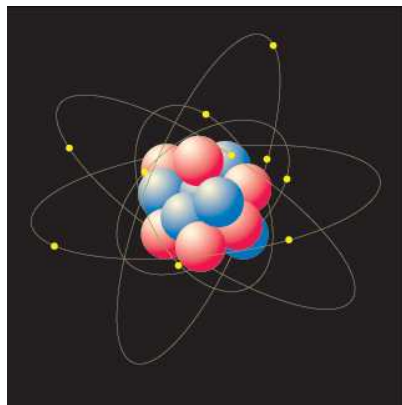
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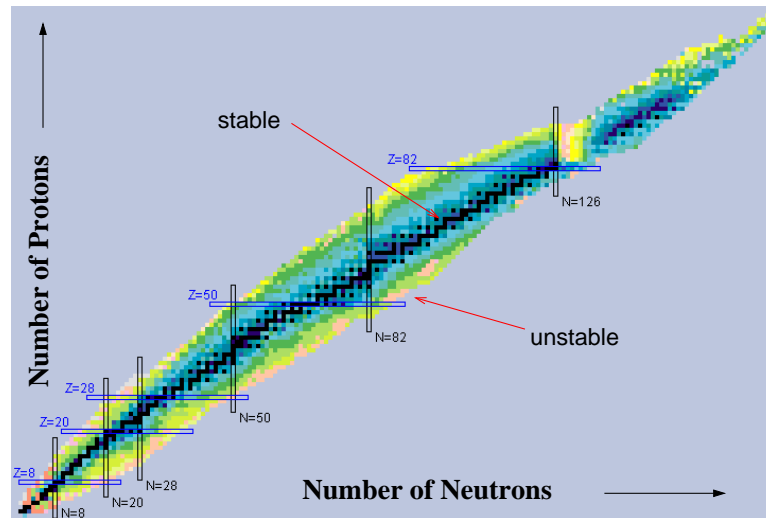
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- Atoms have their own fundamental particles: the electron and the nucleus.
- By 1932 we knew the nucleus consisted of protons and neutrons.

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.

197At	198At	199At	200At	201At	202At	203At	204At	205At	206At	207At	208At	209At	210At	211At	212At	213At
196Po	197Po	198Po	199Po	200Po	201Po	202Po	203Po	204Po	205Po	206Po	207Po	208Po	209Po	210Po	211Po	212Po
195Bi	196Bi	197Bi	198Bi	199Bi	200Bi	201Bi	202Bi	203Bi	204Bi	205Bi	206Bi	207Bi	208Bi	209Bi	210Bi	211Bi
194Pb	195Pb	196Pb	197Pb	198Pb	199Pb	200Pb	201Pb	202Pb	203Pb	204Pb	205Pb	206Pb	207Pb	208Pb	209Pb	210Pb
193Tl	194Tl	195Tl	196Tl	197Tl	198Tl	199Tl	200Tl	201Tl	202Tl	203Tl	204Tl	205Tl	206Tl	207Tl	208Tl	209Tl
192Hg	193Hg	194Hg	195Hg	196Hg	197Hg	198Hg	199Hg	200Hg	201Hg	202Hg	203Hg	204Hg	205Hg	206Hg	207Hg	208Hg
191Au	192Au	193Au	194Au	195Au	196Au	197Au	198Au	199Au	200Au	201Au	202Au	203Au	204Au	205Au		
190Pt	191Pt	192Pt	193Pt	194Pt	195Pt	196Pt	197Pt	198Pt	199Pt	200Pt	201Pt	202Pt				
189Ir	190Ir	191Ir	192Ir	193Ir	194Ir	195Ir	196Ir	197Ir	198Ir							

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?