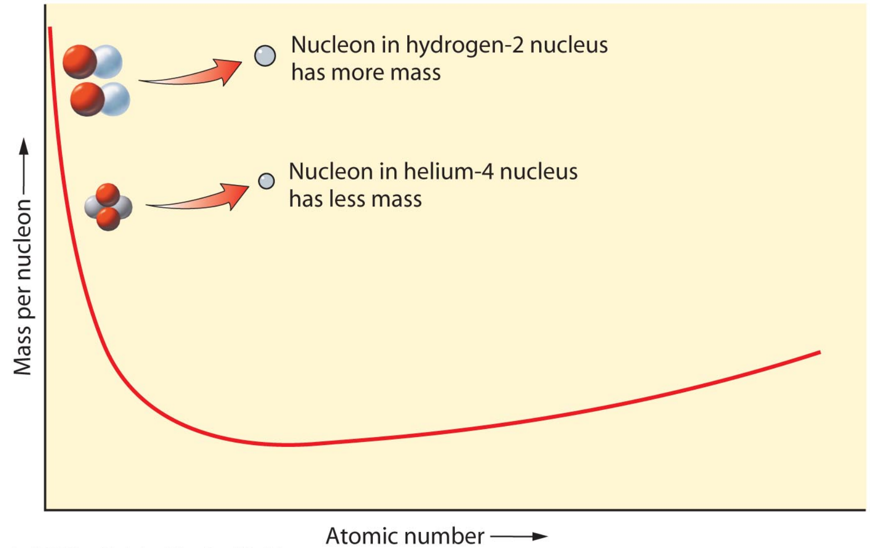
Announcements

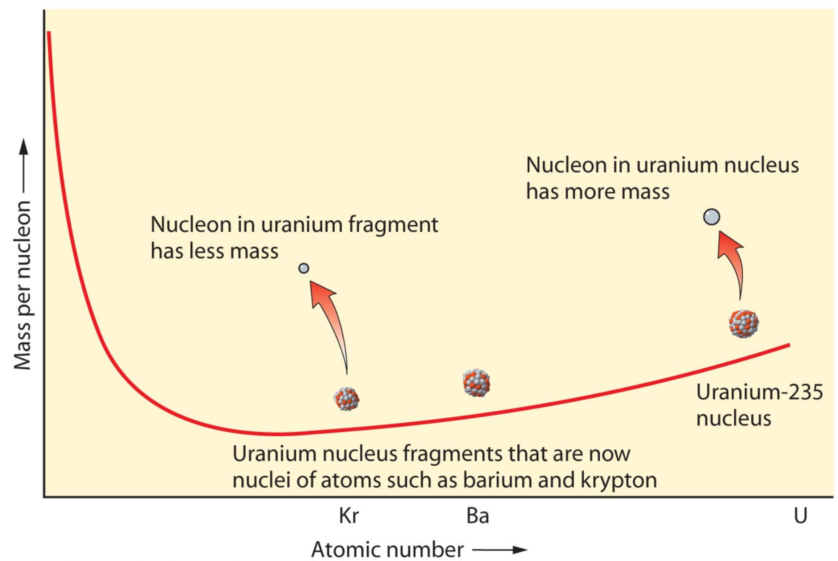
- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- Third hour exam Thursday Dec 6
- The textbook doesn’t cover the material on relativity but in addition to my lecture notes, you can consult the web, for example

  http://www.phys.unsw.edu.au/einsteinlight/#top
- Provide feedback for the course at https://sirsonline.msu.edu starting Nov. 26
  - the email to me said that final grades may be delayed unless you respond
- Final Exam Tuesday Dec 11 7:45-9:45 AM
  - please see me after class if you have a conflict for this time

Fission and fusion

- Are opposites of each other
- For light elements, fusing two particles results in a release of energy
- For heavy elements, fissioning a particle results in a release of energy
- In both cases, the mass afterwards is less than the mass before, with the difference being converted into energy
- $E=mc^2$





Nucleosynthesis

- Big bang: hydrogen and helium
- Inside stars: helium up to iron
- Supernova: all elements heavier than iron

10% of your body is hydrogen; the rest was once inside a star

FRIB will try to recreate the types of nuclear collisions that take place in supernova

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
* *Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

Environmental radiation

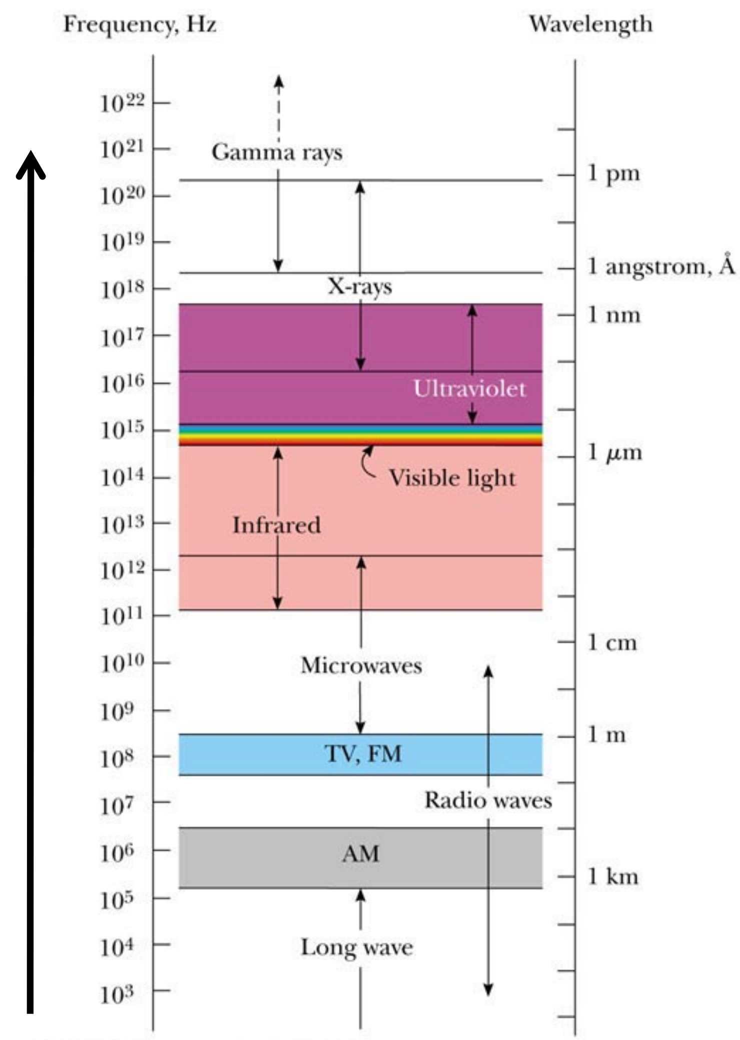
- Radiation doses are measured in units of rems
- Lethal doses begin at 500 rems
  - a person has about a 50% chance of surviving a dose of this magnitude applied during a short time
  - the average dose of radiation per person is about 360 millirems per year
- What do you think is the largest source of radiation exposture?

Radiation

- Cosmic rays: 26 mrem
  - more for pilots, flight attendants
- Ground: 33 mrem
- Our bodies (radioactive potassium): 35 mrem
- Medical procedures: 40 mrem
- X-rays: 15 mrem
- Cathode-ray TV tubes: 11 mrem
- Coal-powered plants: <1 mrem
- Nuclear power plants: <<1 mrem
- **Air (radon): 198 mrem**

What about microwaves?

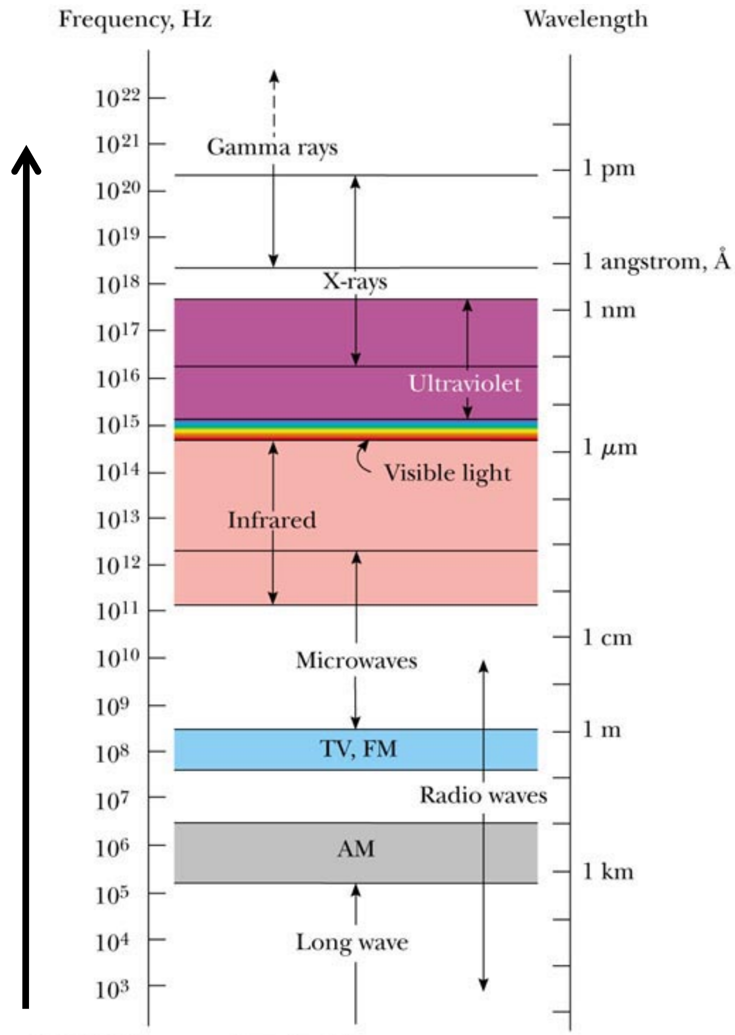
- The energy in each photon of electromagetic radiation is given by E=hf
- In order to cause tissue/genetic damage, the photons have to be energetic
- It's impossible for microwave photons to have enough energy



i.e. cell phones cannot cause cancer

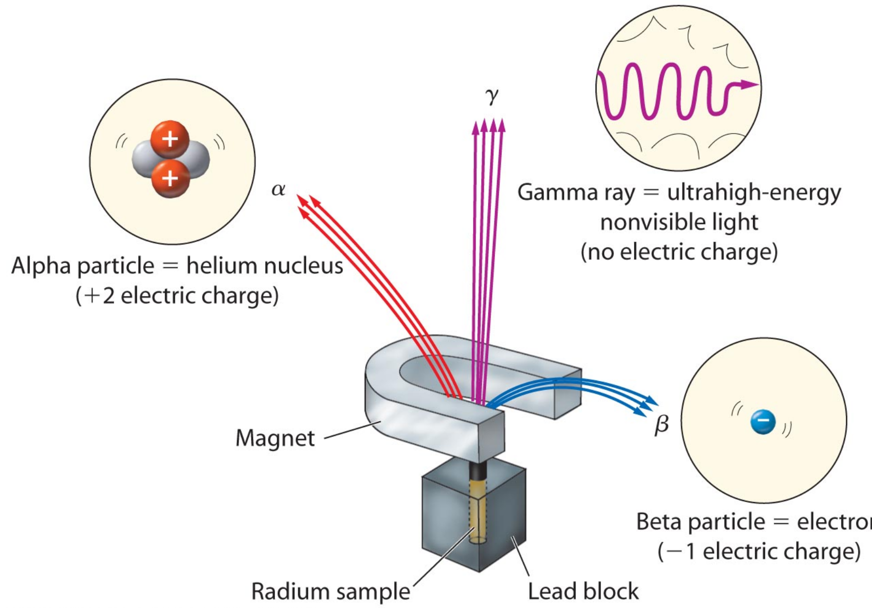
Energies

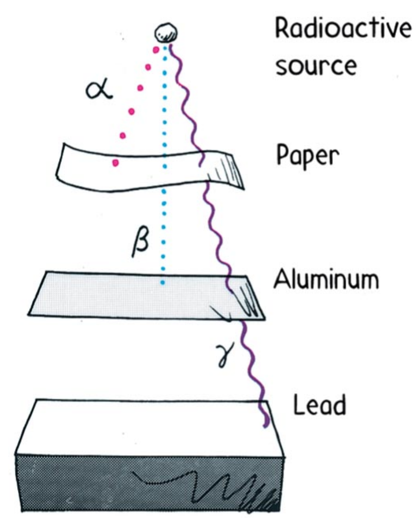
- The unit for energy is Joules
- For high energy particles, we often quote the energy in electron-volts
  - the energy an electron would gain in travelling through a potential change of 1 V
- So visible light has an energy of a few electron-volts
- X-rays have energies of thousands of electron-volts
- The protons at the LHC have an energy of 4 trillion electron-volts
- The conversion is 1 electron-volt=1.6X10^{-19} J
- You should know this conversion and also the acronyms for k(thousand), M(million), G(billion), T(trillion)



Types of radiation

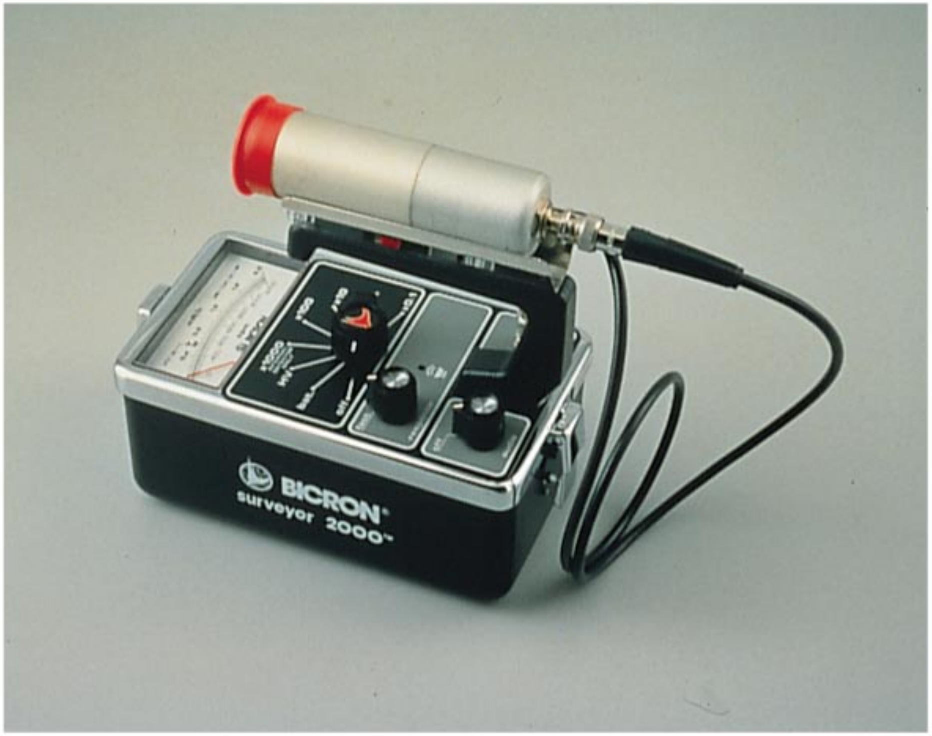
- An alpha particle (the nucleus of a helium atom) can be stopped by a piece of paper
- A thin sheet of aluminum is enough to stop beta particles (electrons)
- Photons are very penetrating and it takes lead to stop them
- Neutrons are also very penetrating





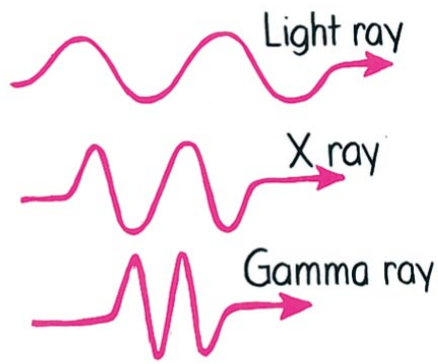
Geiger counter

- Geiger was one of Rutherford's students who discovered the nucleus
- He developed this device for testing for presence of radioactivity
- Any charged particles that pass through active area of counter will cause it to register a count



Food irradiation

- Food can be preserved by exposing it to gamma rays from a radioactive source
- The radiation kills any bacteria in the food
- If you were standing in the way of the gamma radiation, it would kill you as well
- Since it does not change the structure of the nucleus, it does not make the food radioactive



Clicker question

- In both fission and fusion, mass

- A) before and after the event is the same
- B) is created from energy
- C) is converted to energy
- D) increases

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- **C) is converted to energy**
- D) increases

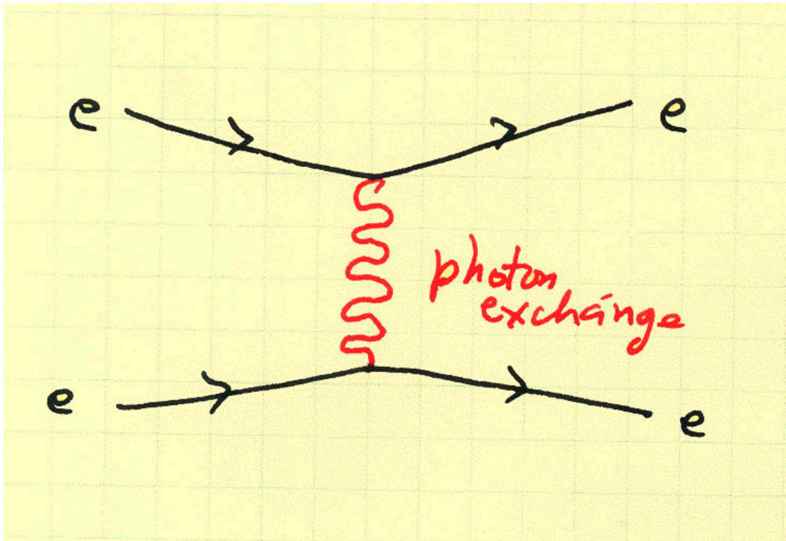
Fundamental Forces

- By mid 1930s, physicists thought they were close to figuring out the fundamental forces acting between particles.

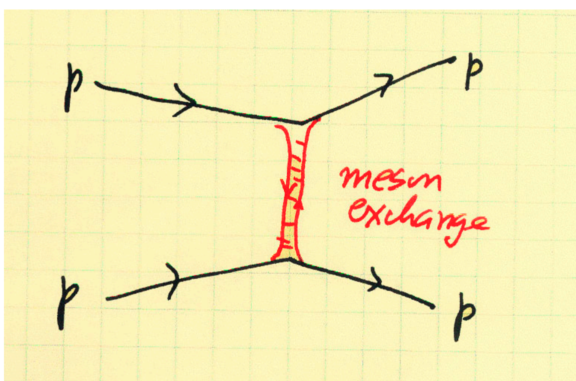
- Forces are explained by ***particle exchange***

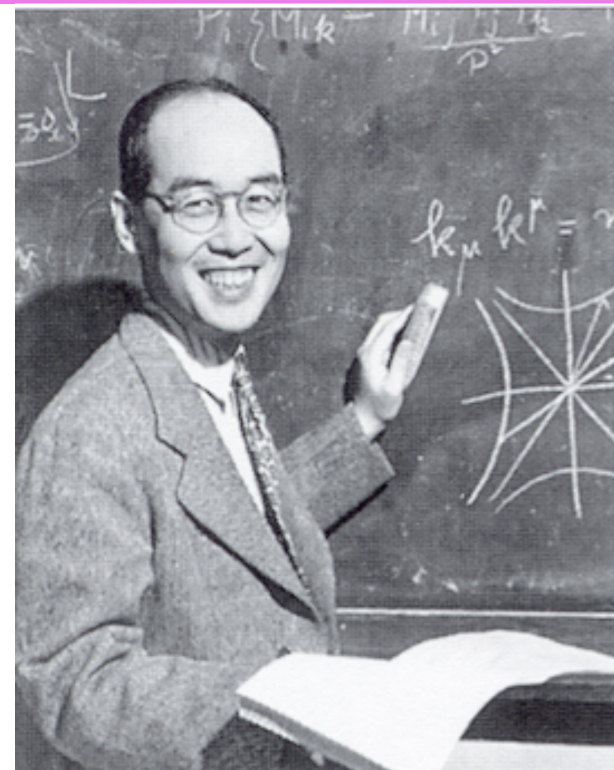
- With the photon, a theoretical picture of the ElectroMagnetic Force had been developed, as …

"*charged particles interacting through the exchange of photons.*"



- Hideki Yukawa suggested a similar model to explain the strong nuclear force that was holding the protons and neutrons together inside the nucleus.

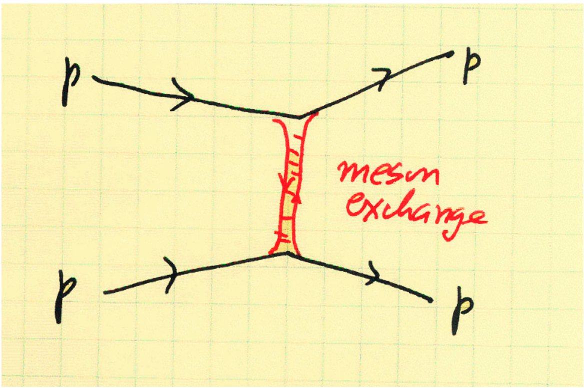




Hideki Yukawa, Japanese physicist (1907 – 1981)

- In Yukawa's theory, ***a new particle was postulated***, whose exchange between nucleons produces the strong force.
- Theoretically, the new particle would have a mass between that of an electron and a nucleon, (~200 m_e). Thus it got the name …

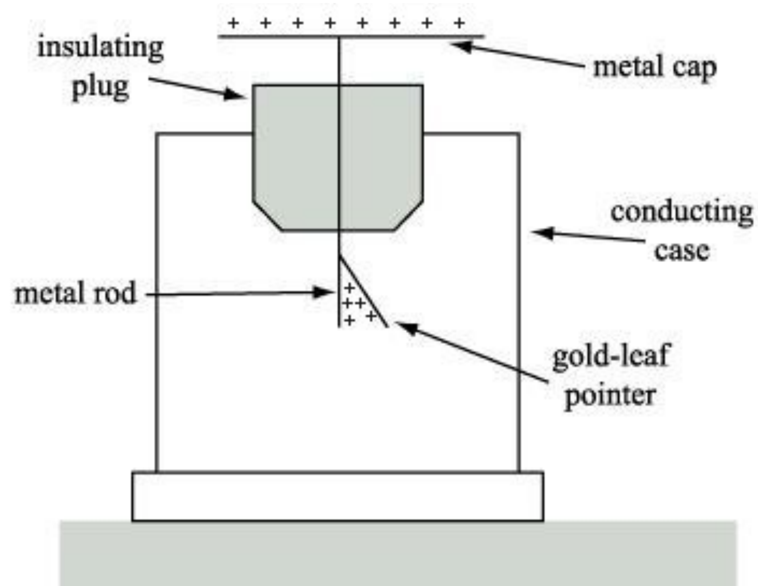
  Meson, Greek for "middle."
- Mesons and related particles were discovered in accelerator experiments in the 1950's and 60's.



Cosmic rays

- The Earth is constantly bombarded by cosmic rays (high energy particles) from outer space
- We' ve already talked about these in the context of muons and special relativity
- The low energy cosmic rays come from the Sun
- The higher energy ones come from very catastrophic processes elsewhere in our galaxy (and from other galaxies)

- The earliest detector for cosmic rays was a device called an electroscope

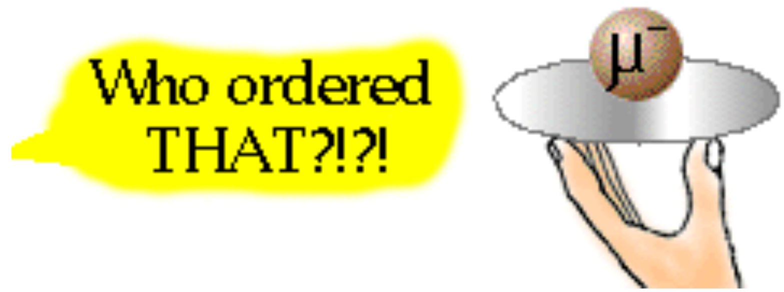


Cosmic rays

- In 1937, physicists looking at cosmic rays found a particle that matched some of the predictions, but did **not** interact strongly
- But during WWII, almost all physics was put on hold
- After WWII, physicists realized that the particle discovered could not the one that Yukawa was talking about
- The 1937 particle is the muon (μ)

Who ordered that?

- Physicists were looking for the pion (needed to describe the strong force), but found the muon instead
- That's often the way science works
- In 1946, a particle that does interact strongly and did have the estimated mass was found
  - pion (π)
- Physicist I.I. Rabi's comment about the muon was "Who ordered that!?"



- Leptons: particles that do not experience the strong force
  - electrons and muons are in this category

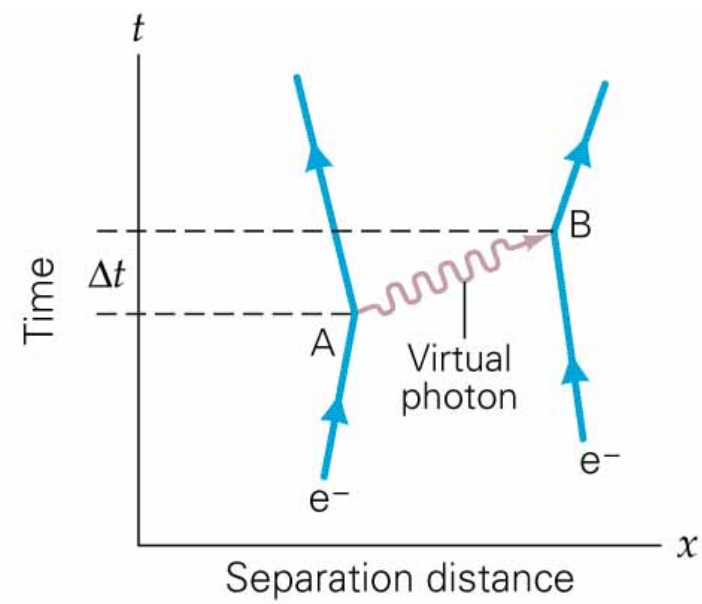
Richard Feynman

Richard Feynman (1918–1988) with his son, Carl, in 1965

- 1947: Feynman develops Quantum Electrodynamics (QED) and his Feynman diagrams.

Feynman Diagrams

- Physicists now have procedures to calculate electromagnetic properties of electrons, positrons, and photons
- Here are two electrons interacting because of the Coulomb force by the exchange of virtual photons



A line that begins and ends in the diagram is a "virtual" particle.

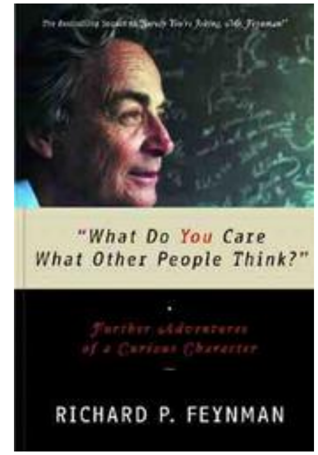
The others are "real" particles.

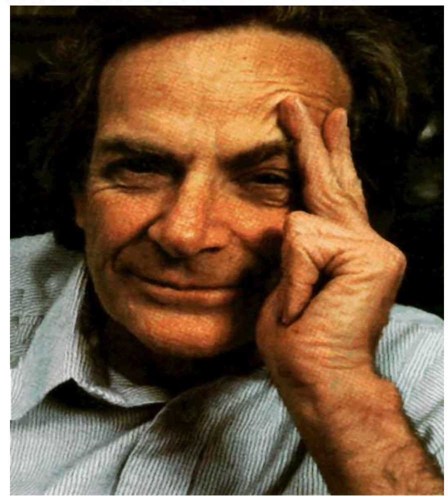
Either read the books…

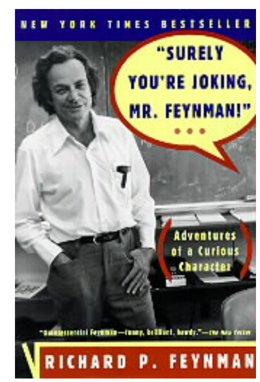
- Most of the public knows him from the investigation of the Challenger disaster
- Also the father of nanotechnology

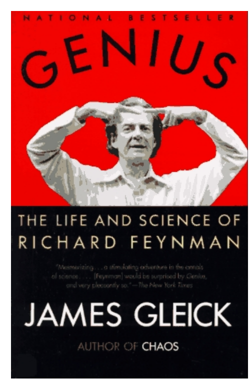
- Some quotes:

- “For those who want some proof that physicists are human, the proof is in the idiocy of all the different units which they use for measuring energy.”
- “I love only nature, and I hate mathematicians.”
- “Physics is like sex: sure, it may give some practical results, but that's not why we do it.”









…or see the movie

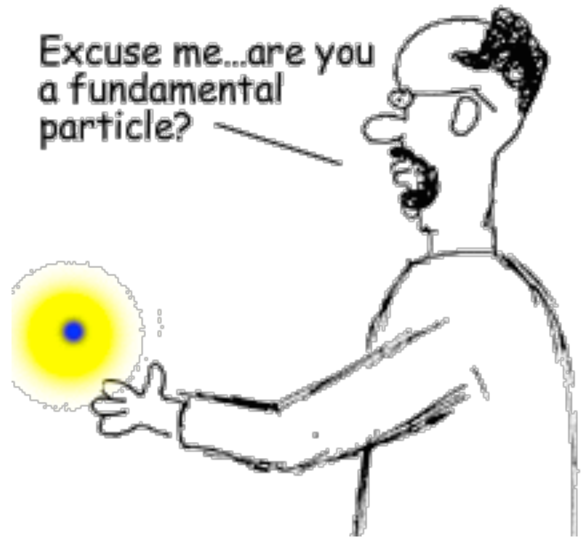
- Matthew Broderick as Richard Feynman in *Infinity*

Accelerators

- In 1948, the Berkeley synchro-cyclotron produces the first artificial pions.
- Thus is launched the era of accelerators to produce and discover new particles- High Energy Physics.

It’s a Jungle Out There!

- Through the 1950s and on to the 1960s, a large assortment of particles were discovered.
- Currently the number of such particles is greater than 200!
- The large number prompted Enrico Fermi to say:
  - “If I could remember the names of all of these particles, I would have been a botanist”



A Classification of Particles

- There emerged a classification system for all these particles. Generally speaking there were three broad categories:
- *Photons*, which seemed to be in a category by itself.
- *Hadrons*- that interact through the strong force, with two sub categories or classes
  - *Mesons* – particles smaller than proton
  - *Baryons (Greek for Heavy)*- particles same size or larger than proton
- *Leptons (Greek for small or light)*- group of particles that participate in the weak force. All are smaller than the lightest hadron.
  - Examples include: electron, muons, and neutrinos.
  - Leptons appear to be truly elementary, with no structure (ie they seem point-like)

- The Lepton family seemed to be small- only 6 members (electron, muon and the tau; with each there was an associated neutrino)
- All the new particles being discovered were hadrons.

Tables of particles

TABLE 30.2 Some Particles and Their Properties

Category	Particle Name	Symbol	Anti-particle	Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Lifetime(s)	Principal Decay Modes[a]
Leptons	Electron	e^-	e^+	0.511	0	+1	0	0	0	Stable	
	Electron–Neutrino	ν_e	$\bar{\nu}_e$	$<7\ eV/c^2$	0	+1	0	0	0	Stable	
	Muon	μ^-	μ^+	105.7	0	0	+1	0	0	2.20×10^{-6}	$e^-\bar{\nu}_e\nu_\mu$
	Muon–Neutrino	ν_μ	$\bar{\nu}_\mu$	<0.3	0	0	+1	0	0	Stable	
	Tau	τ^-	τ^+	1784	0	0	0	+1	0	$<4 \times 10^{-13}$	$\mu^-\bar{\nu}_\mu\nu_\tau$, $e^-\bar{\nu}_e\nu_\tau$
	Tau–Neutrino	ν_τ	$\bar{\nu}_\tau$	<30	0	0	0	+1	0	Stable	
Hadrons											
Mesons	Pion	π^+	π^-	139.6	0	0	0	0	0	2.60×10^{-8}	$\mu^+\nu_\mu$
		π^0	Self	135.0	0	0	0	0	0	0.83×10^{-16}	2γ
	Kaon	K^+	K^-	493.7	0	0	0	0	+1	1.24×10^{-8}	$\mu^+\nu_\mu$, $\pi^+\pi^0$
		K^0_S	$\bar{K}^0_S$	497.7	0	0	0	0	+1	0.89×10^{-10}	$\pi^+\pi^-$, $2\pi^0$
		K^0_L	$\bar{K}^0_L$	497.7	0	0	0	0	+1	5.2×10^{-8}	$\pi^\pm e^\mp\bar{\nu}_e$, $3\pi^0$ $\pi^\pm\mu^\mp\bar{\nu}_\mu$
	Eta	η	Self	548.8	0	0	0	0	0	$<10^{-18}$	2γ, 3π
		η'	Self	958	0	0	0	0	0	2.2×10^{-21}	$\eta\pi^+\pi^-$
Baryons	Proton	p	$\bar{p}$	938.3	+1	0	0	0	0	Stable	
	Neutron	n	$\bar{n}$	939.6	+1	0	0	0	0	920	$pe^-\bar{\nu}_e$
	Lambda	Λ^0	$\bar{\Lambda}^0$	1115.6	+1	0	0	0	−1	2.6×10^{-10}	$p\pi^-$, $n\pi^0$
	Sigma	Σ^+	$\bar{\Sigma}^-$	1189.4	+1	0	0	0	−1	0.80×10^{-10}	$p\pi^0$, $n\pi^+$
		Σ^0	$\bar{\Sigma}^0$	1192.5	+1	0	0	0	−1	6×10^{-20}	$\Lambda^0\gamma$
		Σ^-	$\bar{\Sigma}^+$	1197.3	+1	0	0	0	−1	1.5×10^{-10}	$n\pi^-$
	Xi	Ξ^0	$\bar{\Xi}^0$	1315	+1	0	0	0	−2	2.9×10^{-10}	$\Lambda^0\pi^0$
		Ξ^-	$\bar{\Xi}^+$	1321	+1	0	0	0	−2	1.64×10^{-10}	$\Lambda^0\pi^-$
	Omega	Ω^-	Ω^+	1672	+1	0	0	0	−3	0.82×10^{-10}	$\Xi^0\pi^0$, Λ^0K^-

[a] Notations in this column such as $p\pi^-$, $n\pi^0$ mean two possible decay modes. In this case, the two possible decays are $\Lambda^0 \rightarrow p + \pi^-$ and $\Lambda^0 \rightarrow n + \pi^0$.

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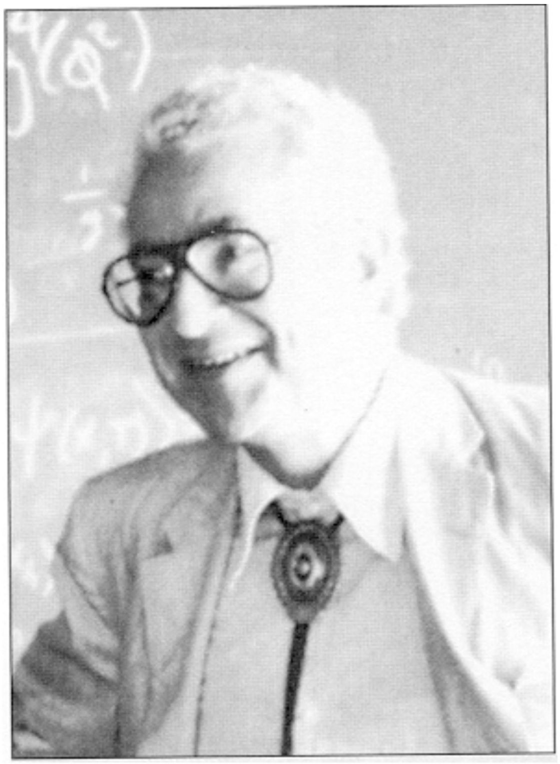
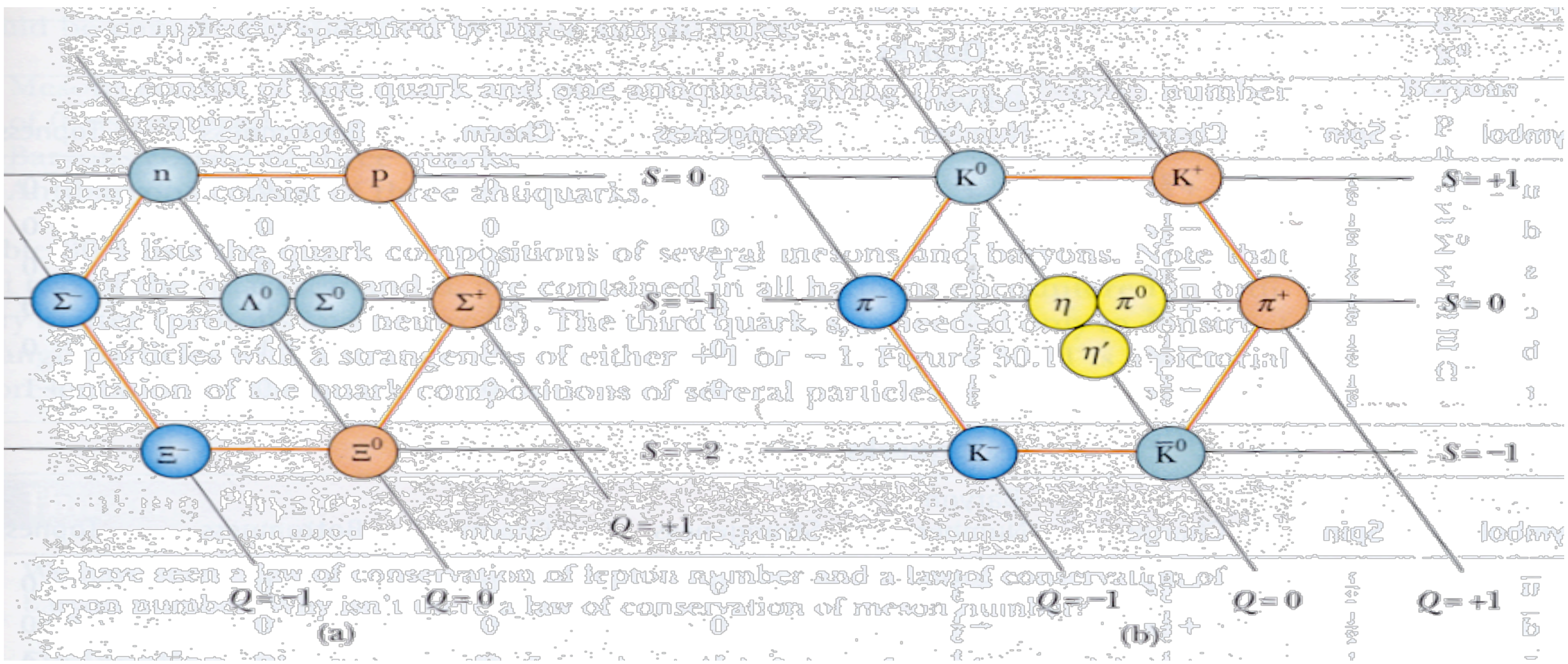
Murray Gell-Mann



Murray Gell-Mann,
American physicist (1929–   )

- Starting in the early 1960s, Gell-Mann tries a variety of ways to organize the vast zoo of particles being discovered.

- He is guided by the example of the periodic table of elements.
- Eventually he hit upon the “Eight-fold Way”
- With the symmetry of the pattern, it was possible to discover “missing” particles, such as the Ω^- particle
- In addition, the pattern hinted at an underlying structure.



Quarks

- 1963: Gell-Mann and George Zweig independently suggested a more elementary structure for hadrons.
- The early model proposed that all hadrons are composed of two or three fundamental constituents, each with their own fractional charge, either 1/3e or 2/3e.
- Whimsically, Gell-Mann names them "*Quarks*" from a line in James Joyce's Finnegan's Wake
- "Three quarks for Muster Mark!"

Quark flavors

- Simply put,
  - mesons consist of a quark and an antiquark.
  - baryons consisted of three quarks.
- Originally there were three (up, down, and sideways)
- Further research has led to 6