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

Nuclear interlude: Isotopes

- The number of protons in a nucleus determines which element it is
 - which equals the number of electrons in a normal atom
- But there can be different isotopes of a particular element
 - same number of protons, but different number of neutrons

atomic weight

(# protons + # neutrons)

___ symbol for element

atomic number (# protons)

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The most common isotope $^{238}_{92}U$ of uranium is 238, with 238-92=146 neutrons

About 0.7% of uranium is the $^{235}_{92}U$ isotope 235, which has the ^{92}U same number of protons (otherwise it wouldn't be uranium), but 3 less neutrons

Nuclei

- The atomic nucleus only occupies a few quadrillionths of the total volume of the atom
 - most of the atom is empty space
- The nucleus consists of protons and neutrons packed closely together
- Since the protons are positively charged and they all repel each other, there must be another still stronger force that keeps the nucleus together
 - the strong force
- The strong force is short range, acting over ~10⁻¹⁵ m, or about the size of a proton or neutron
 - the electromagnetic force has an infinite range



All nucleons, both protons and neutrons, attract one another by the strong nuclear force.

Only protons repel one another by the electric force.

The more protons in a nucleus, the more neutrons are needed to keep the nucleus bound. Smaller nuclei are more stable than larger nuclei, because of the short range of the strong nuclear force.

All nuclei having more than 83 protons are very unstable, i.e. are radioactive.

Neutrons



- Neutrons outside of a nucleus are not stable and decay into a proton, electron (and neutrino) with a half-life of about 10 minutes (see discussion of half-life later)
- This can happen inside of a nucleus as well, with the beta (electron) being emitted
 - thus the number of protons increases by one
- A nucleus can also emit an alpha particle (2 protons and 2 neutrons)

Radioactive decays

- When a ²³⁸U nucleus ejects an alpha particle, the nucleus loses 2 protons and 2 neutrons
- The nucleus left behind is now thorium
- We can write this reaction as

$$^{238}_{92}U \rightarrow ^{232}_{90}Th + ^{4}_{2}He$$

2 protons plus
2 neutrons is just
the nucleus of a
Helium atom

- ²³⁴Th is also radioactive
- When it decays, it emits a beta particle
 - a neutron then becomes a proton
- It now has 91 protons, so becomes a different element, proactinium
- We can write this reaction as

$$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + e^{-1}$$

Half-life

- The rate of decay for a radioactive isotope is characterized by its half-life, the amount of time it takes for half of the ^{1/2} nuclei to decay
- Half-lives can vary a great deal depending on the type of radioactive decay
 - from a millionth of a second to billions of years



Half-lifes, again

- A half-life, T_{1/2}, is the amount of time it takes half of the atoms in a radioactive substance to decay
- Why do particular atoms decay at a particular time?
- It is part of the random nature of quantum mechanics and can not be calculated for an individual atom
 - "God playing dice"
- The curve for a radioactive decay is given by the formula on the right
- If I start off with N_o atoms, and I end up with N atoms after a time t, I can solve for t if I know T_{1/2}



Example

- Suppose I have a sample with 1024 radioactive atoms, and I wait 6 half-lives. How many atoms are left?
- After 1 half-life, 512
- After 2 half-lives, 256
- After 3 half-lives, 128
- After 4 half-lives, 64
- After 5 half-lives, 32
- After 6 half-lives, 16
- The number of atoms is reduced by a factor of 2⁶=64



Example

- Suppose I wait 2.0 half-lives (2.0 X /T_{1/2})
- How many atoms are left from the original sample?
- Well, we know that ½ of them are lost after the first half-life and ½ of what is left are lost after the second half-life
 - 0.5X0.5=0.25
- We can also use the formula on the right

$$N / N_o = e^{-\frac{0.693t}{T_{1/2}}} = e^{-\frac{(0.693) * 2 * T_{1/2}}{T_{1/2}}} = e^{-1.386} = 0.25$$

 Suppose I wait 2.5 half-lives; then I plug in 2.5 in the equation above rather than 2



Radioactive dating

- The Earth's atmosphere is constantly bombarded by cosmic rays
- These reactions produce high energy particles which then can interact with other atoms in the atmosphere
- If I have a high energy neutron interacting with a nitrogen nucleus, it becomes an isotope of carbon (¹⁴C)
- Carbon-14 is radioactive but has the same chemical properties as (normal) carbon-12
- Plants take in carbon-14 through carbon dioxide

- After they die, they stop taking in carbon dioxide, and thus carbon-14
- The half-life of carbon-14 is 5730 years
- By examining the amount of carbon-14 in a material compared to the amount of carbon-12, we can perform a radioactive dating of the material
- Works up to about 50,000 years



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11,460 years 5730 years



ago







Fission bomb

- Most of the naturally occurring uranium is the ²³⁸U isotope
- Only the ²³⁵U isotope can be used for fuel/bomb, so the two have to be separated
 - it took more than 2 years during WWII to make enough for 1 bomb
- There will be no explosion unless a critical mass of ²³⁵U is present
 - otherwise the neutrons escape from the bomb before triggering more reactions
 - about 1 kg
- In one bomb design, a piece of uranium is fired towards a hollow sphere of uranium
 - each is sub-critical, but together they make a critical mass



Neutrons escape surface



Fission reactors

- The energy released in the nuclear fissions is used to produce steam which is then used to drive a turbine
 - use only slightly enriched uranium, so no explosion possible
- About 20% of the power in the US is by nuclear power (about 90% in France)
- Have to worry about radioactive waste products (but burning coal releases both uranium and thorium)



Fusion

- Fission is not how the sun (or any star) is powered
 - not very efficient and stars are mostly hydrogen and helium anyway
- Stars are powered by fusion reactions, such as hydrogen atoms colliding at high energies, forming helium, and releasing energy
 - note that these are isotopes of hydrogen (deuterium and tritium)
- The helium atom has less mass than 2 protons and 2 neutrons together
- The difference is released as energy...a lot of energy
- 4000000 tons of mass are converted to energy every second in the sun





Fusion reactors

- Fusion takes place only at very high temperatures (such as at the center of the sun), on the order of 10's of millions of degrees
- If we can re-create those conditions, then we can produce fusion reactions that give off energy, using hydrogen (basically water) as fuel
 - the trick is re-creating those conditions
- There are two approaches
 - hitting a fuel pellet containing hydrogen simultaneously with powerful lasers
 - confining a plasma of hydrogen with a strong magnetic field and then heating it up until fusion reactions start taking place
- No radioactive by-products, but very difficult technically
 - Research has been going on for about 50 years, and still far away from commerical reactor



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Hydrogen bomb



- Can be 1000 times as powerful as atomic bomb
- Uses a fission bomb to trigger fusion of isotopes of hydrogen (deuterium and tritium)
- If I had shown this diagram 60 years ago, I probably would have been arrested

Edward Teller

- The 'father' of the US hydrogen bomb was Edward Teller
 - if you wanted to piss him off, you could call him the mother of the hydrogen bomb (since he acted on an idea from Stanislaw Ulam)
- He was the inspiration for the movie character Dr. Strangelove
- At the end of the movie, the Earth is destroyed





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



Nucleosynthesis

• B	ig b	bang: hydrogen and helium													10% of your body is						
• Ir	Inside stars: helium up to iron														hydrogen; the rest was						
• S	Supernova: all elements heavier than iron														once inside a star						
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K	Ca		Sc	Ťi	V	Cr	Mn	Fe	Co	Ňi	Cu	Zn	Ga	Ge	As	Se	Br	Kr			
39.098 rubidium	40.078 strontium		44.956 yttrium	47.867 zirconium	50.942 niobium	51.996 molybdenum	54.938 technetium	55.845 ruthenium	58.933 rhodium	58.693 palladium	63.546 silver	65.39 cadmium	69.723 indium	72.61 tin	74.922 antimony	78.96 tellurium	79.904 iodine	83.80 xenon			
37	38		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54			
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55	56	57-70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86			
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132.91 francium	137.33 radium		174.97 lawrencium	1/8.49 rutherfordium	180.95 dubnium	183.84 seaborgium	186.21 bohrium	190.23 hassium	192.22 meitnerium	195.08 ununnilium	196.97 unununium	200.59 ununbium	204.38	207.2 ununquadium	208.98	[209]	[210]	[222]			
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[223]	Ka	**	[262]	[261]	DD [262]	3g	BN [264]	HS [269]													
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*Lanthanida series	lanthanum 57	cerium 58	praseodymium 59	neodymium 60	promethium 61	samarium 62	europium 63	gadolinium 64	terbium 65	dysprosium 66	holmium 67	erbium 68	thulium 69	ytterbium 70
Lanthannue Series	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	138.91	140.12	140.91	144.24	[145]	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.04
	actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium
* * Actinide series	89	90	91	92	93	94	95	96	97	98	99	100	101	102
	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No
	[227]	232.04	231.04	238.03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[250]

Clicker question

- Of alpha, beta and gamma radiation, two are high speed massive particles and one is not
- The one that isn't is

- A) alpha
- B) beta
- C) gamma
- D) all are different forms of electromagnetic waves

Clicker question

- Of alpha, beta and gamma radiation, two are high speed particles and one is not
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• A) alpha

• B) beta

- C) gamma
- D) all are different forms of electromagnetic waves