

“I have to keep going, as there are always people on my track. I have to publish my present work as rapidly as possible in order to keep in the race. The best sprinters in this road of investigation are Becquerel and the Curies...” Letter to his mother (1902), Ernest Rutherford, New Zealand-English physicist (1871-1937)

“It was necessary at this point to find a new term to define this new property of matter manifested by the elements of uranium and thorium. I proposed the word radioactivity which has since become generally adopted; the radioactive elements have been called radio elements.”

Marie Curie, Polish-French physicist (1867-1934)

“No-one really thought of fission before its discovery.”

Lise Meitner, Austrian-Swedish physicist (1878-1968)

Current Assignments ...

For today

- Read Sections 13.6-13.7, 14.1-14.2

For Lecture 23

- Sects. 14.3-14.4, 15.1-15.4, Ch. 17

**Office hours:
3-4 Tuesdays
& Thursdays**

Homework #4

- Posted March 7. [Late deadline 11 AM, March 29.](#)

Homework #5

- Posted March 21. Due 11:00 AM, Friday, April 5

Writing Assignment #2

- Posted Feb. 28. Due 11:00 AM, Thursday, April 4

Suggested Conceptual Exercises

- Chapter 14: 1,3,5,7,9,11,13,15,17,19,21,23,25,27,29

Tutorial #10

Review of Lecture 21

Textbook, Sections 13.2-13.6

- The effect of observation
- Quantum nonlocality
- Quantum entanglement
- Toward a post-Newtonian worldview
- Spectroscopy and observing atomic spectra

Plan for Lecture 22

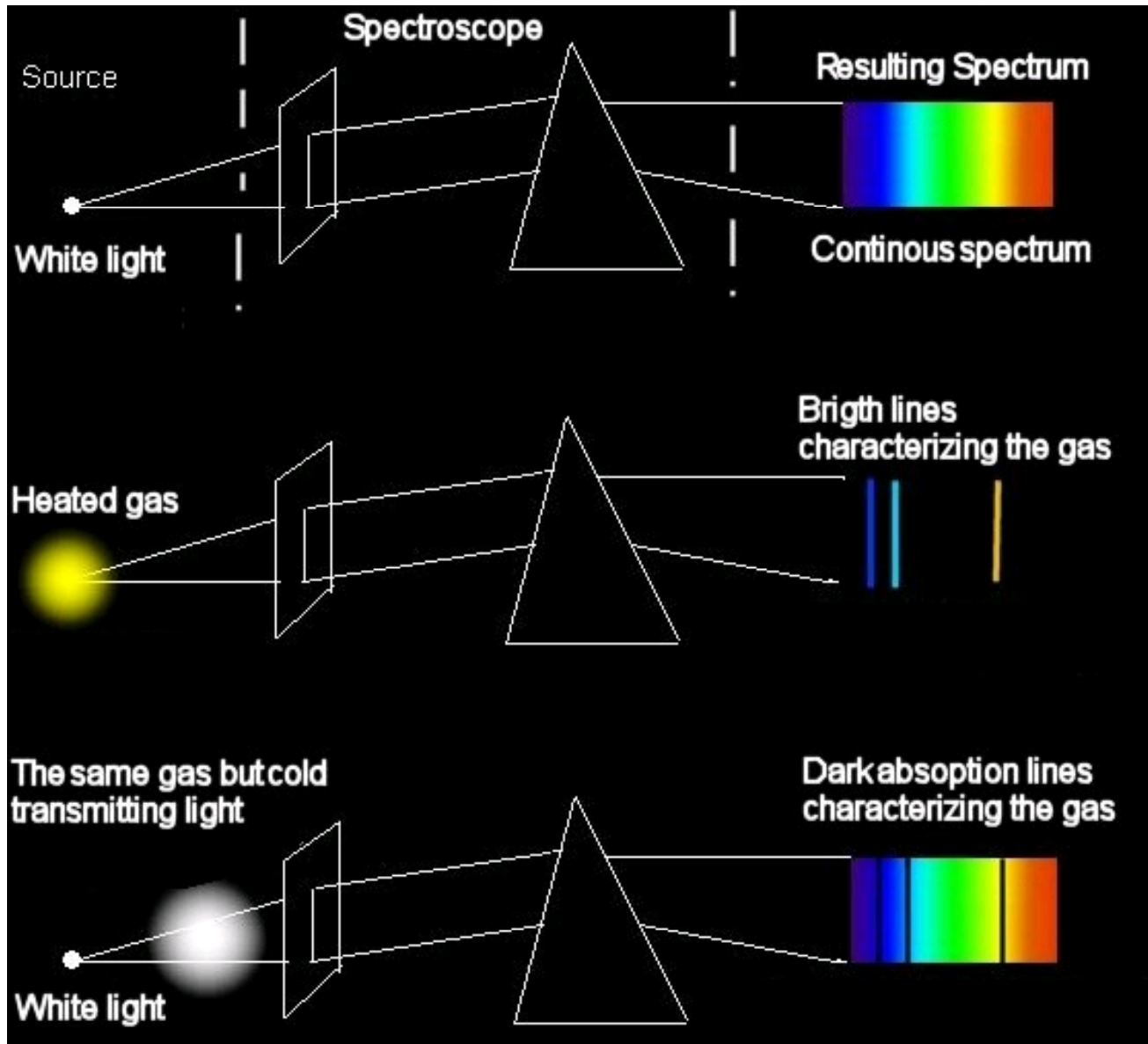
Textbook, Sections 13.6-13.7

- Observing atomic spectra
- Models of the atom
- The quantum atom
- Energy transitions in atoms

Textbook, Sections 14.1-14.2

- The strong nuclear force
- Nuclear structure

Examples of Spectra



Continous spectrum
- hot source
(solid or liquid)

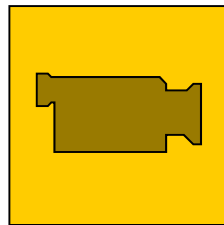
Line spectra -
dilute gas
either emitting
or absorbing

<http://www.amateur-spectroscopy.com/Spectroscope.htm>

Interactive Examples of Spectra

- MiniSpectroscopy displays a visual representation (a "spectroscope view") of a sample spectrum simultaneously with a graphical (intensity vs. wavelength) representation.

<http://mo-www.harvard.edu/Java/MiniSpectroscopy.html>

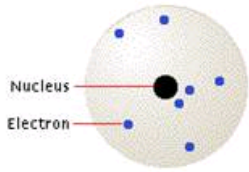


Observing Atomic Spectra

- A gas can be excited by heat and by sending an electric current through it.
- But why does a thin gas emit only certain frequencies of light?

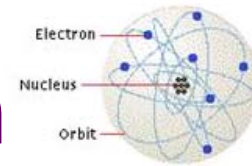
Textbook Figure 13.14

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The Rutherford Model
pictured the atom as a miniature solar system with the electrons moving like planets around the nucleus.

Models of the Atom



The Bohr Model
'quantized' the orbits in order to explain the stability of the atom.

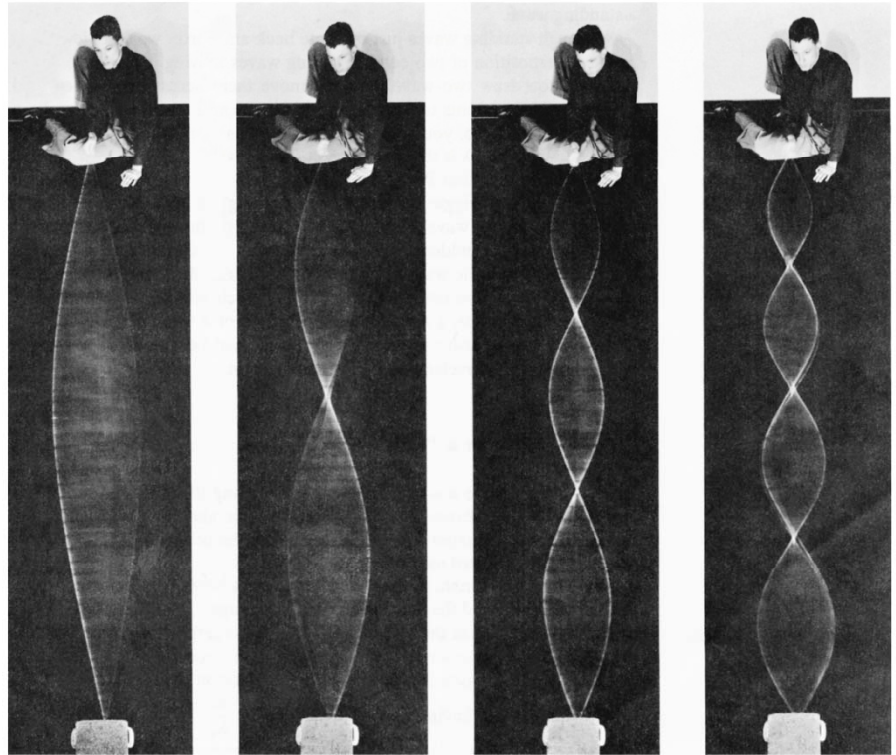
http://superphysics.netfirms.com/pp_quantum_theory.html

- To answer this question, we need to consider the atom again.
- Recall Lecture 8 - we discussed early models of the atom
 - billiard ball, plum pudding, planetary model
- 1913 - Bohr model of the atom (very briefly!)
 - stable orbits in which the electron can exist without radiating and thus not spiralling into the nucleus (but no theoretical justification)
 - each spectral line is due to energy lost when the electron falls from a higher to lower orbit (but only works for atoms with one electron)

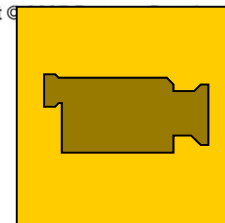
Standing Waves

(towards a quantum model of the atom)

- Matter waves, like other waves, can form standing waves.
- There must be an integral number of half-waves for the wave to persist.
- The wave does not move along the string, but the string always has a wave pattern.



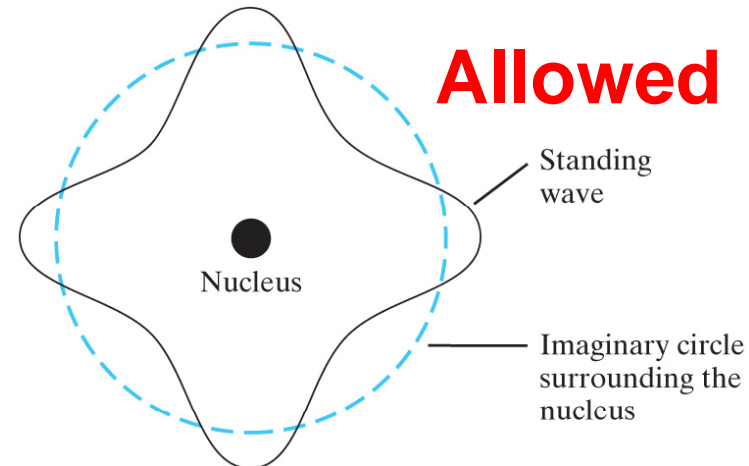
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<http://faraday.physics.utoronto.ca/IYearLab/Intros/StandingWaves/Flash/sta2fix.html>

The Quantum Atom

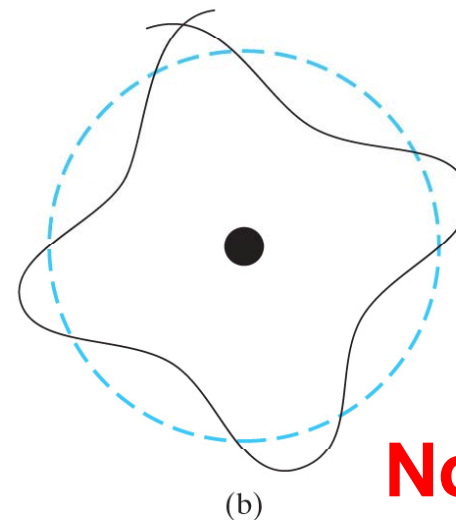
- The matter waves of the electron form circular standing waves.
- The wave must just fit around the atomic nucleus.
- The only allowed orbits of the electron are those for which this is true.



Allowed

(a)

Hydrogen
atom =
one proton +
one electron



Not allowed

(b)

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Quantum States of the Hydrogen Atom: 10 possible electron distributions around the atom (there are more)

Textbook Figure 13.18

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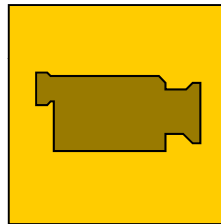
These are 3D solutions
to Schroedinger's
Equation.

Darker shading
indicates more intense
matter field and higher
probability that the
electron will be there.

Quantum States of Hydrogen Atom

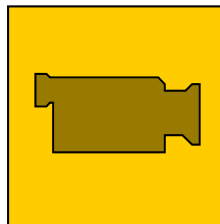
- What does a hydrogen atom look like?

http://www.hydrogenlab.de/elektronium/HTML/einleitung_hauptseite_uk.html



- Hydrogen atom orbital viewer

<http://www.falstad.com/qmatom/>



Try these at home.

Energy Level Diagrams

- Each quantum state is a standing wave with a specific frequency and a specific energy.
- The lowest energy level is called the ground state, and the rest are called excited states.

Textbook
Figures 13.18 & 13.19

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Quantum Jumps

- When an electron makes a quantum jump from one quantum state to another, it makes a transition from one energy level to another.
- The atom emits/absorbs radiation if it jumps to a lower/higher energy level.
- Emitted/absorbed photon has energy

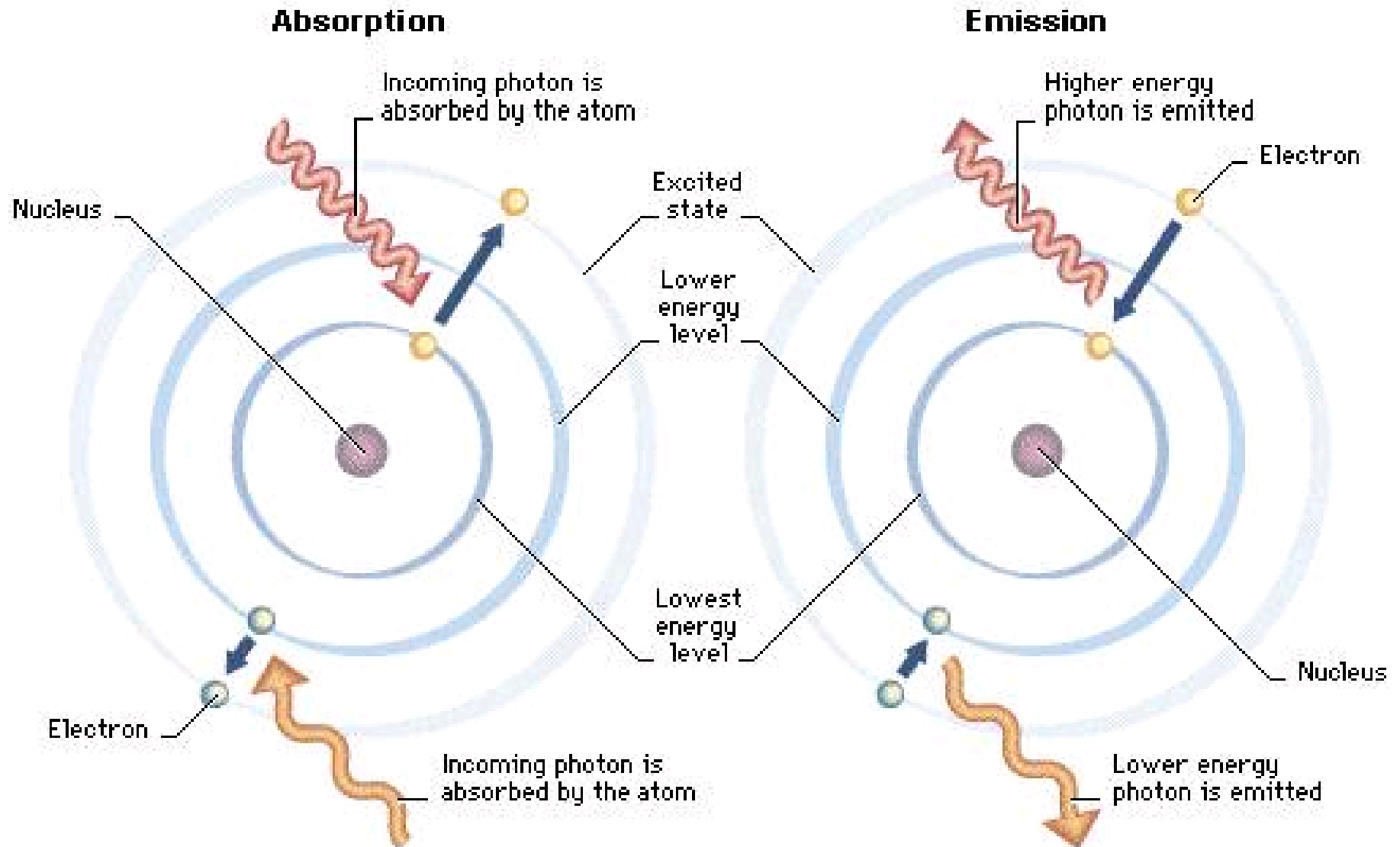
$$hf = E_{\text{high-energy state}} - E_{\text{low-energy state}}$$

Textbook Figure 13.20

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Emission of a photon

Absorption and Emission (schematic diagram of atom!)



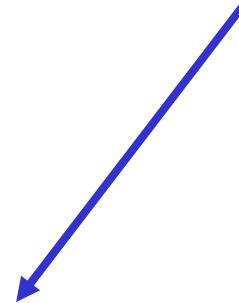
All possible transitions between energy levels for the first five levels of the hydrogen atom

← Energy levels

Textbook
Figures 13.21 & 13.22

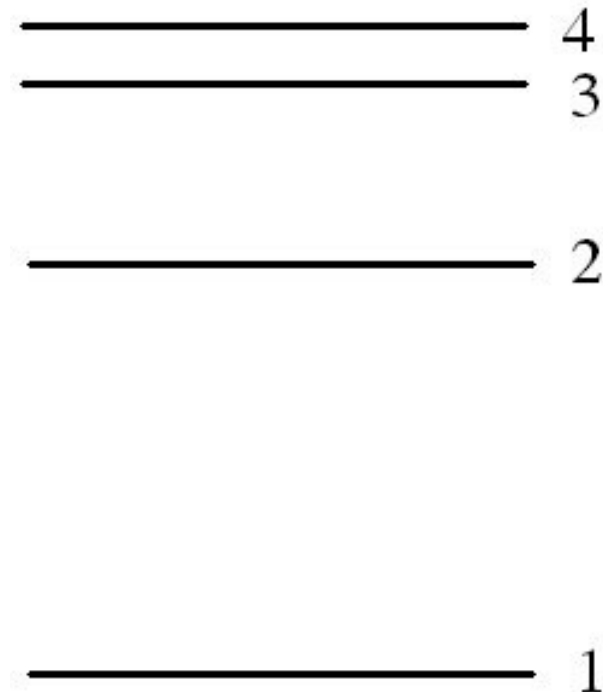
Emitted photon
frequencies

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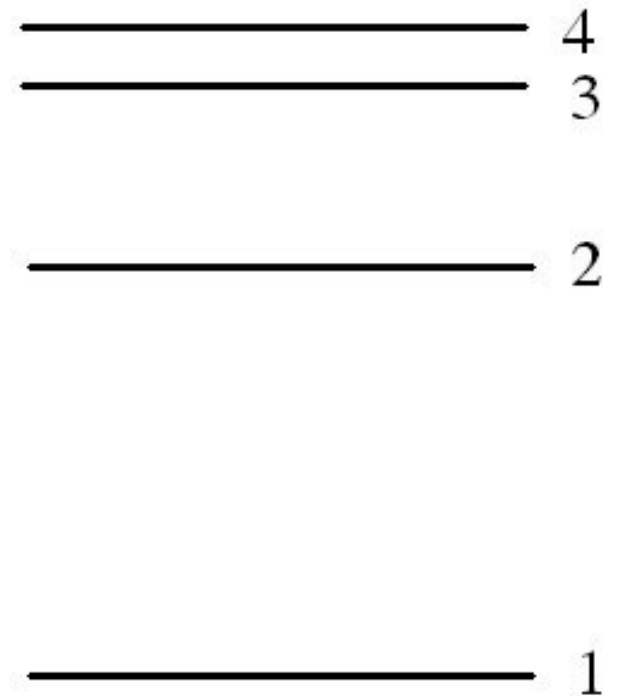
A certain type of atom has only four energy levels, as shown in the diagram. The "spectral lines" produced by this element are all visible, except for one ultra-violet line. The quantum jump that produces the UV line is

- (A) state 2 to 1
- (B) state 4 to 1**
- (C) state 4 to 3
- (D) state 1 to 4
- (E) impossible to determine without further information



A certain type of atom has only four energy levels, as shown in the diagram. The total number of spectral lines emitted by this element is

- (A) 3
- (B) 4
- (C) 6**
- (D) 10
- (E) impossible to determine without further information



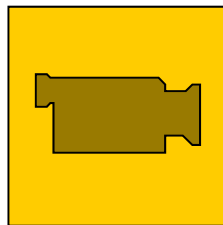
Models of the Hydrogen Atom

Using spectroscopy to test models of the hydrogen atom

- <http://serc.carleton.edu/sp/compadre/interactive/examples/19268.html>

or

- <http://phet.colorado.edu/simulations/hydrogen-atom/hydrogen-atom.jnlp>



A Simplified View of the Nucleus

Neutrons - uncharged



Protons - positively charged



**Textbook
Figure 14.1**

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Why doesn't
electrical repulsion
cause the nucleus to
fly apart?

The Strong Nuclear Force

- A “new” force, called the strong nuclear force, holds the nucleus together.
 - It acts over distances of about 10^{-15} m, attracting protons and neutrons.
- There is one other force, called the weak nuclear force, which is responsible for some forms of radioactive decay.
- Four fundamental forces – gravity, electromagnetism, strong and weak nuclear forces.
 - Responsible for the structure of our universe.
 - Every other force can be reduced to one of these four.

The Size of the Strong Force

- The strong nuclear force is the strongest of the four forces. Why? quantum physics...
 - If a proton or neutron is confined to the nucleus, the Uncertainty Principle requires that its velocity be about 10% of the speed of light, so its kinetic energy is very large.
 - Similarly, if an electron is confined to the volume of an atom, its speed must be about 0.5% of the speed of light.
 - The energy difference between an electron moving at 0.5% of c and a proton moving at 10% of c yields the difference in strength between chemical and nuclear reactions.

Some Definitions

- A nuclear reaction is any process that alters the structure of a nucleus.
 - Both protons and neutrons are important.
- Atomic number = the number of protons (also = number of orbital electrons)
 - This determines the element of the atom.
- The number of neutrons determines the isotope of the element.
- [Atomic] mass number = the total number of protons plus neutrons.
 - An isotope is labeled by its atomic number and its mass number.

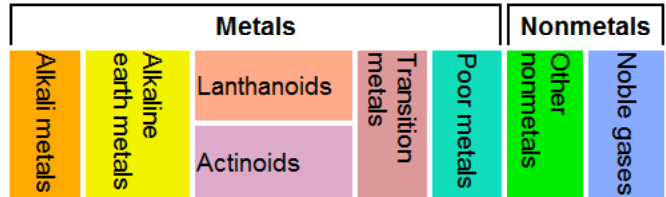
Periodic Table of Elements

Atomic number

Atomic mass
 \approx mass number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.00794																2 He Helium 4.002602	
3 Li Lithium 6.941	4 Be Beryllium 9.012182																10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050																18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.887	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.9334	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (209.9824)	85 At Astatine (208.9871)	86 Rn Radon (222.0176)
87 Fr Francium (223)	88 Ra Radium (226)	89-103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

- C** Solid
- Hg** Liquid
- H** Gas
- Rf** Unknown



For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.03806	91 Pa Protactinium 231.03688	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

How do the mass and charge of a ^{14}C nucleus compare with those of a ^{12}C nucleus?

- (A) The mass of ^{14}C is 50% larger, while the charge is the same.
- (B) Both the mass and the charge of ^{14}C are the same as those of ^{12}C .
- (C) Both the mass and charge of ^{14}C are one-sixth larger.
- (D) The mass is the same, while the charge of ^{14}C is one-sixth larger.
- (E)** The mass of ^{14}C is one-sixth larger, while the charge is the same.

