"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 ...

Office hours:
3-4 Tuesdays
& Thursdays

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

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

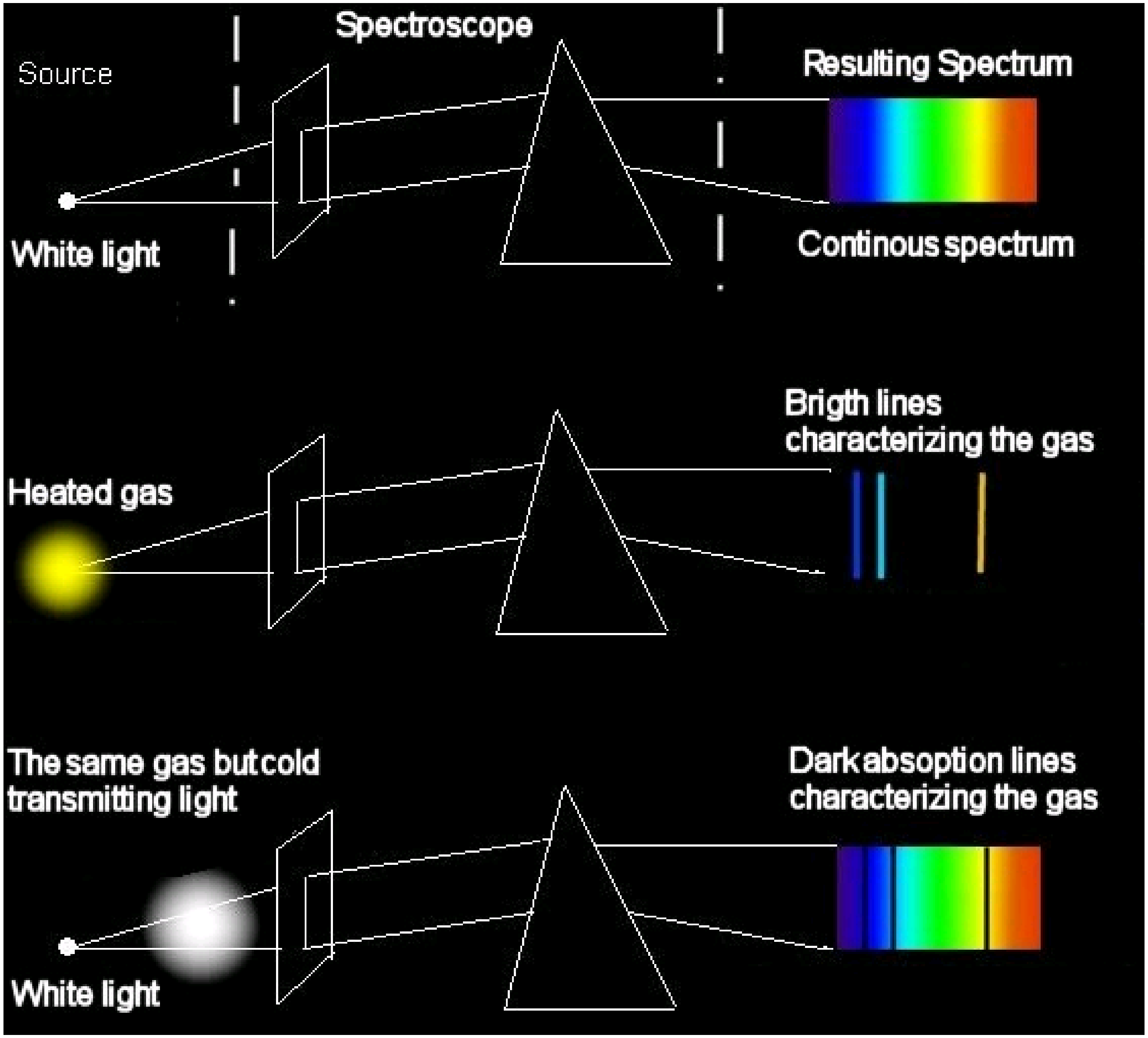
Textbook, Sections 13.6-13.7

- 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)

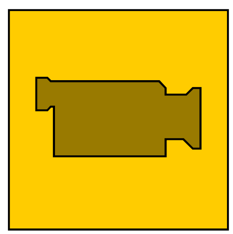
Line spectra - dilute gas either emitting or absorbing

http://www.amateurspectroscopy.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.

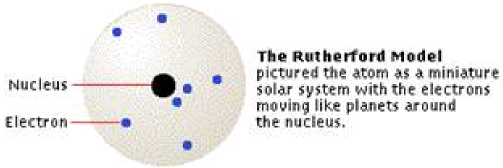
http://mo-www.harvard.edu/Java/MiniSpectroscopy.html



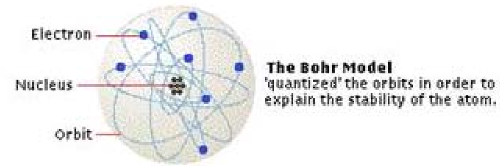
Observing Atomic Spectra

- 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



Models of the Atom

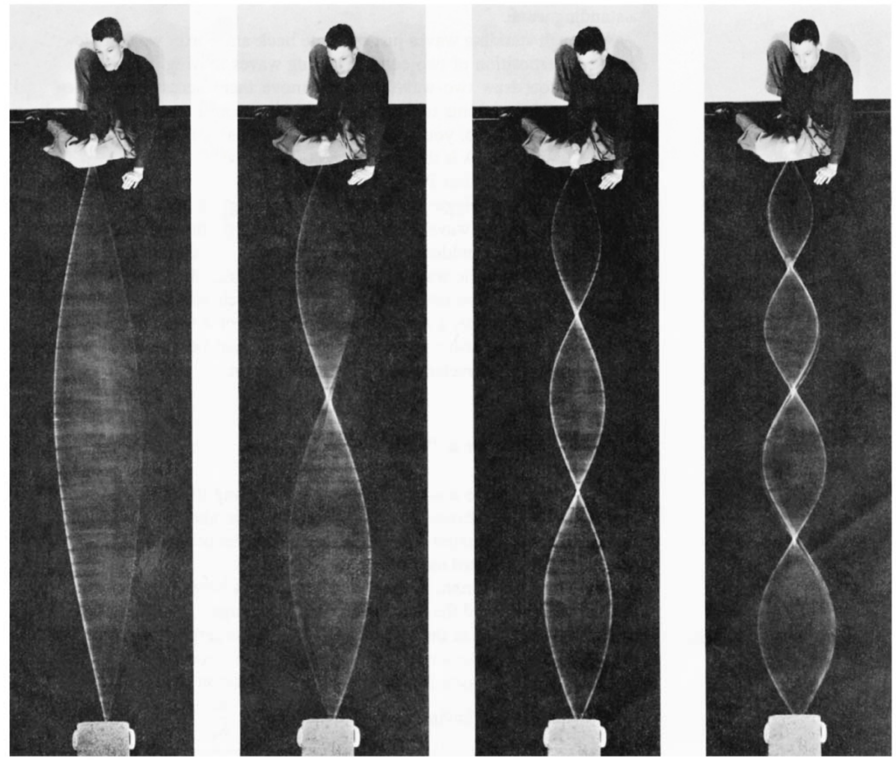


http://superphysics.netfirms.com/pp_quantum_theory.html

- 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 <u>standing waves</u>.
- 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.

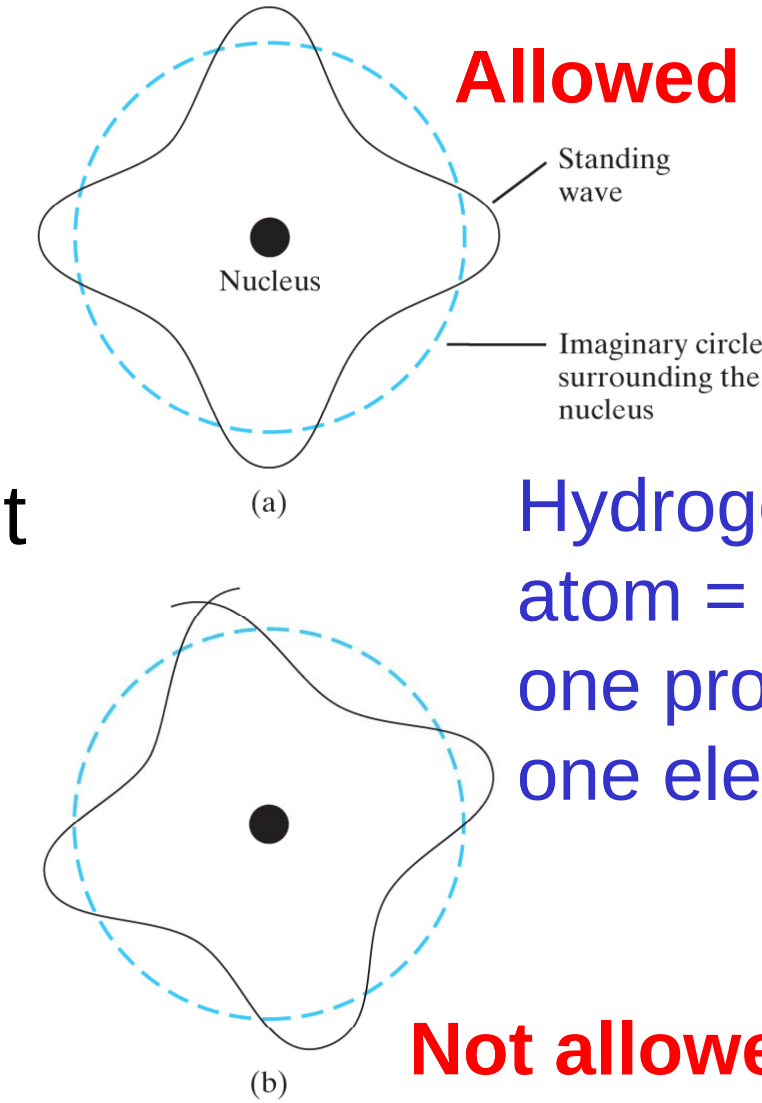


http://faraday.physics.utoronto.ca/IYearLab/Intros/StandingWaves/Flash/sta2fix.html

The Quantum Atom

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

Allowed



Not allowed

Hydrogen atom = one proton + one electron

Quantum States of the Hydrogen Atom:

10 possible electron distributions around the atom (there are more)

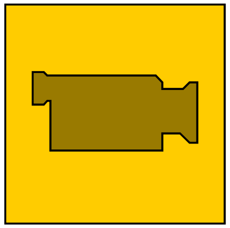
Textbook Figure 13.18

These are 3D solutions to Schroedinger's Equation.

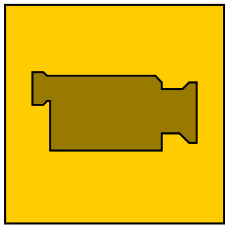
Darker shading indicates more intense matter field and higher probability that the electron will be there.

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

Quantum Jumps

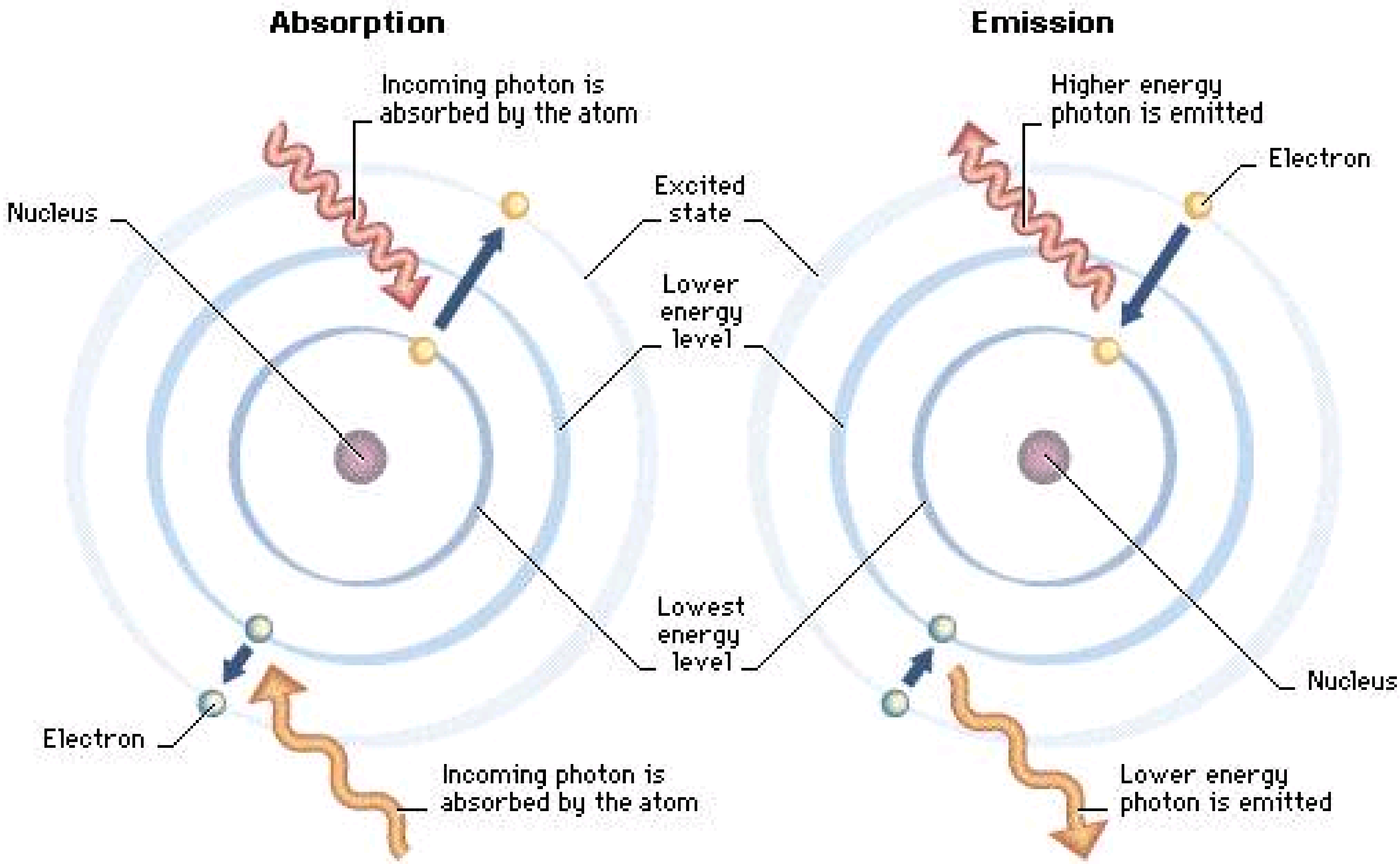
- When an electron makes a quantum jump from one quantum state to another, it makes a transition from one energy level to another.
- The atom emits/absorbs radiation if it jumps to a lower/higher energy level.
- Emitted/absorbed photon has energy

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

Textbook Figure 13.20

Emission of a photon

Absorption and Emission (schematic diagram of atom!)



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

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

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

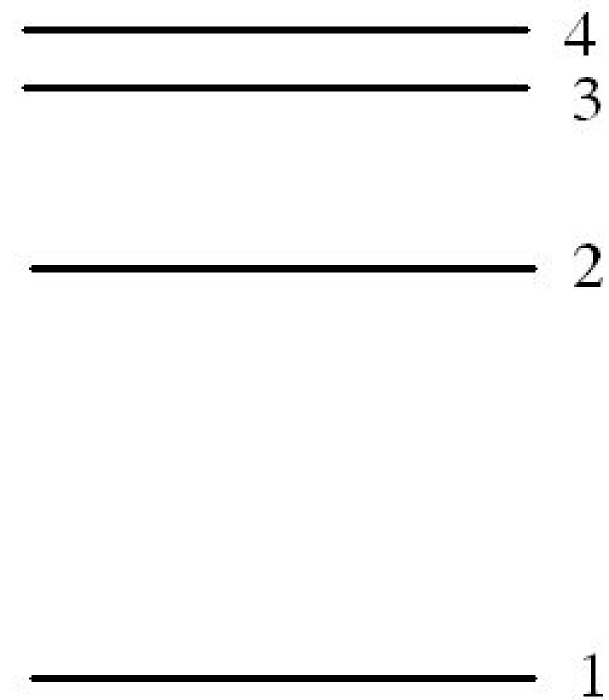
(A) state 2 to 1

(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

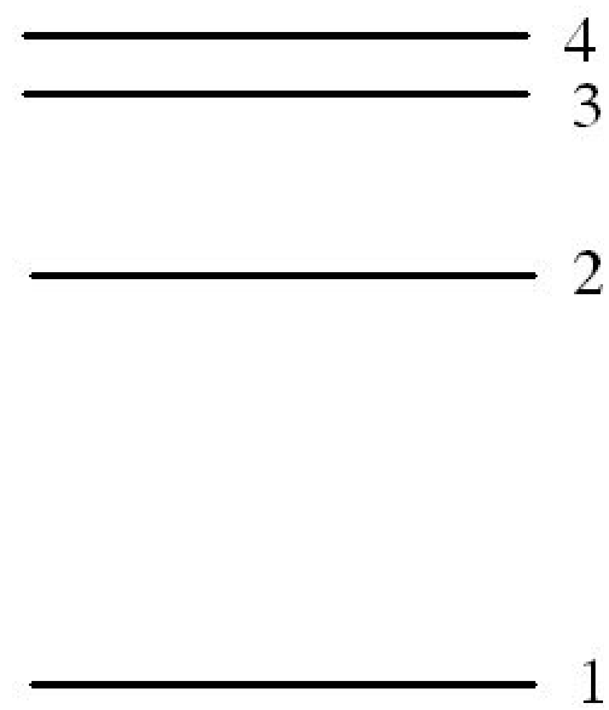
(A) 3

(B) 4

(C) 6

(D) 10

(E) impossible to determine without further information



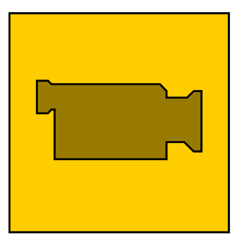
Models of the Hydrogen Atom

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

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, electro-magnetism, 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.

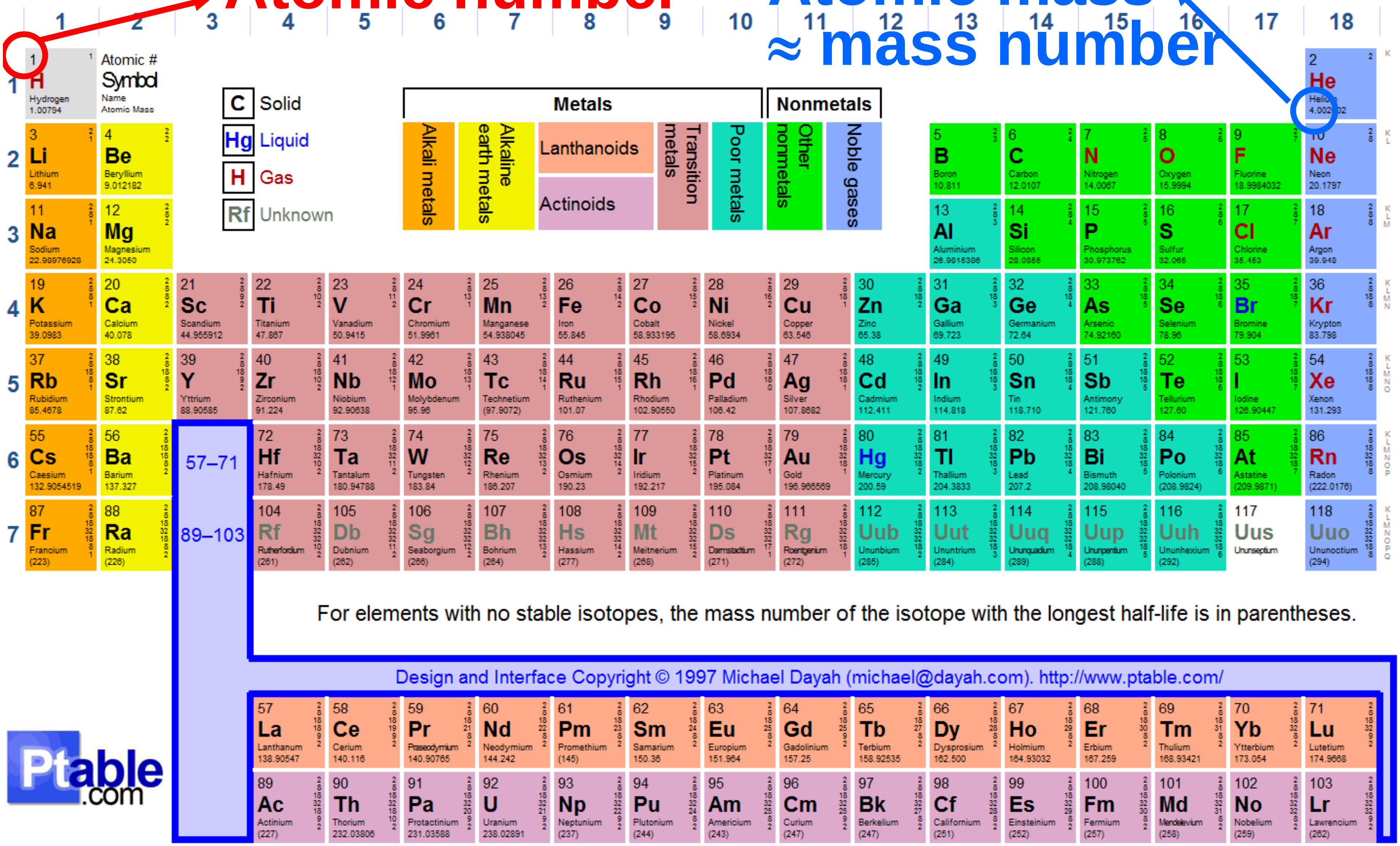
Some Definitions

- 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 ≈ mass number



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.

How many protons and how many neutrons are in the $^{56}_{26}Fe$ (iron) nucleus?

(A) 26 protons and 30 neutrons

(B) 26 protons and 56 neutrons

(C) 30 protons and 26 neutrons

(D) 56 protons and 26 neutrons

(E) None of the above

$^{56}_{26}Fe$ indicates mass number / atomic number Chemical symbol

atomic number = number of protons

mass number = number of protons + number of neutrons