Course evaluations today
Please fill out course evaluation.
Start lecture - 12:15 pm

No lab this week
Optional review Fri. Dec. 12, 12:05 pm, 2103 Ch.

Week15HW covers material for final, but does not count toward HW grade.

Final Exam is
Mon Dec 15, 10:05 am - 12:05 pm
2103 Chamberlin
3 equation sheets allowed
About 30% on new material
Rest on topics of exam1, exam2, exam3.

Summary of 3D atoms
- Electron quantum state labeled by 4 quantum #s ($n, \ell, m_\ell, m_s$)
- For any 1-electron atom (e.g. hydrogen)
  - State energy depends only on $n$
- Multi-electron atoms
  - One electron / quantum state
  - State energy also depends on $\ell$
  - Fill lowest energy first
- Photon emitted if electron transitions to lower energy state.

How do atomic transitions occur?
- How does electron in excited state decide to make a transition?
- One possibility: spontaneous emission
  - Electron "spontaneously" drops from excited state
    - Photon is emitted

Another possibility: Stimulated emission
- Atom in excited state.
- Photon of energy $hf = \Delta E$ "stimulates" electron to drop.
- Additional photon is emitted,
  Same frequency,
  in-phase with stimulating photon

Before

$$hf = \Delta E$$

After

If excited state is ‘metastable’ (long lifetime for spontaneous emission) stimulated emission dominates

LASER: Light Amplification by Stimulated Emission of Radiation
Atoms ‘prepared’ in metastable excited states
...waiting for stimulated emission
Called ‘population inversion’
(atomic family in ground state)
Excited states stimulated to emit photon from a spontaneous emission.
Two photons out, these stimulate other atoms to emit.

Ruby Laser
- Ruby crystal has the atoms which will emit photons
- Flash tube provides energy to put atoms in excited state.
- Spontaneous emission creates photon of correct frequency, amplified by stimulated emission of excited atoms.
Ruby laser operation

- Relaxation to metastable state (no photon emission)
- Transition by stimulated emission of photon

Atoms so far...

- Electrons orbiting around positively-charged nucleus
- Quantum mechanics determines shape (probability distribution) of orbits (quantum state)
- 1 electron per quantum state
- # of electrons determines chemical properties, hence which element.
- But what about the nucleus...

Chap 43: Nuclear Physics

- Nucleus: protons and neutrons
  - Protons have a positive electrical charge
  - Neutrons have zero electrical charge (are neutral)
  - Neutrons & protons generically called ‘nucleons’
- Spacing between these nucleons is ~ $10^{-15}$ m
- Nucleus is 5,000 times smaller than the atom

Carbon

- Carbon has 6 protons, 6 electrons ($Z=6$): this is what makes it carbon.
- Most common form of carbon has 6 neutrons in the nucleus. Called $^{12}$C.
- Another form of carbon has 6 protons, 8 neutrons in the nucleus. This is $^{14}$C.

Question

Hydrogen is the element with one electron. Which of the following is NOT the nucleus of an isotope of hydrogen?

A. One proton
B. One proton and one neutron
C. Two protons and one neutron

Heavy Water: deuterium oxide

$D_2O$: two $^2H$, one $^{16}O$ bonded together

How much heavier is $D_2O$ than $H_2O$?

A. 5 %
B. 10%
C. 15%
D. 50%
Heavy Water Properties

- Biological effects
  - Hydrogen bond w/ D slightly stronger than w/ H
  - Slows down, or stops, reactions in which bond is broken
  - Rats die when 50% of body water is D2O
  - 25% deuteration causes sterility in mice, rats, dogs

Nuclear matter

- Any particle in nucleus, neutron or proton, is called a nucleon.
- “A” is atomic mass number
  - A=total number of nucleons in nucleus.
- Experimental result
  - All nuclei have about the same (incredibly high!) density of 2.3x10^{17} kg/m^3
  - Volume ∝ A = number of nucleons
  - Radius ∝ A^{1/3}
    - r = r_oA^{1/3}, \ r_o = 1.2 \text{ fm} = 1.2 \times 10^{-15} \text{ m}

What holds nucleus together?

- New force: strong nuclear force
- Strength:
  - Stronger than Coulomb force at short distances (overcomes Coulomb repulsion).
  - Decreases more quickly with distance than Coulomb
  - Not noticeable at large separations
- Electric charge dependence:
  - Doesn’t depend on sign of charge
  - Attractive between all nucleons (proton & neutron)

Nuclear masses

- Nuclear masses very accurately measured.
- New unit of measurement
  - Atomic Mass Unit: 1 u = 1.6605x10^{-27} kg
  - Defined so that mass of \textit{^{12}C} is exactly 12 u.
- Proton mass
  - m_p = (1.6726x10^{-27} kg) / (1u/1.6605x10^{-27} kg)
  - m_p = 1.0073\text{ u}
- Neutron mass
  - m_n = (1.6749x10^{-27} kg) / (1u/1.6605x10^{-27} kg)
  - m_n = 1.0087\text{ u}
Nuclear masses

<table>
<thead>
<tr>
<th>Isolated protons &amp; neutrons</th>
<th>Protons &amp; neutrons bound in He nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0073 u</td>
<td></td>
</tr>
<tr>
<td>1.0073 u</td>
<td></td>
</tr>
<tr>
<td>1.0087 u</td>
<td></td>
</tr>
<tr>
<td>1.0087 u</td>
<td></td>
</tr>
<tr>
<td>4.0320 u</td>
<td>4.0015 u</td>
</tr>
</tbody>
</table>

\[ \text{Difference!} \]

Binding energy

- Work required to separate nucleons
- According to Einstein’s mass-energy equivalence,

\[ E = mc^2 \]

\[ = (0.0305 \text{ u})(1.661 \times 10^{-27} \text{ kg/u})(c^2) \]

\[ = (0.0305 \text{ u})(931.494 \text{ MeV/u}) \]

\[ = 28.41 \text{ MeV} \Rightarrow 7.1 \text{ MeV/nucleon} \]

Binding energy: energy required to break apart nucleus into individual nucleons

Mass difference: 1 u of mass equivalent energy

= 28.41 MeV \Rightarrow 7.1 MeV/nucleon

Atomic masses well-known -> easier to use

Binding energy/nucleon

- Calculate binding energy from masses

\[ E_{\text{binding}} = \left( Zm_p + Nm_n - m_{\text{nucleus}} \right)c^2 \]

\[ = \left( Zm_p + Nm_n - m_{\text{atom}} \right)c^2 \]

Mass of Hydrogen atom (1.0078 u)

Mass of atom with Z protons, N neutrons

Radioactivity

- Other isotopes have less binding energy (higher total energy)
  - Less stable
- If energy too high,
  - nucleus spontaneously changes to lower energy configuration.
  - Does this by changing nucleons inside the nucleus.
- These nuclei are unstable, and are said to decay.
- They nuclei are radioactive.

Radioactive nuclei

- Equal # neutrons and protons