Great Idea:
All of the matter around us is made of atoms, the chemical building blocks of our world.

Chapter Outline

• The Smallest Pieces
• The Structure of the Atom
• When Matter Meets Light
• The Periodic Table of the Elements

The Smallest Pieces

• Democritus
  – Cut matter to reach smallest piece
  – Called “the atom” or “uncuttable”
  – All material formed from atoms

• John Dalton
  – Father of modern atomic theory
  – Cannot break down elements
  – Elements composed of atoms
  – Example: Water molecule is 1 oxygen atom and 1 hydrogen atom
iClicker Question

• Greek philosophers came up with the idea of "atom" which roughly translates as
  - A small
  - B uncuttable
  - C reactive

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• An atom is
  - A the smallest representative sample of water
  - B something that can be cut in half and still be the same
  - C the smallest representative sample of an element

Are Atoms Real?

• Evidence for the reality of atoms
  - Behavior of a gas
  - Chemical combinations
  - Radioactivity
  - Brownian motion
  - X-ray crystallography
  - Atomic-scale microscopy

The Behavior of a Gas

• Bernoulli
  - atoms have mass & velocity and thus kinetic energy
• Decreasing volume increases pressure (A)
• Increasing temperature increases pressure (B)

Chemical Combinations

• Dalton applied law of definite proportions
  - Elements combine in a specific ratio of weights
    - Ex: Water is 8 parts oxygen to 1 part hydrogen
  - Ratio of weights is a small whole number
    - Ex: 12 lbs Carbon can combine with either 16 lbs or 32 lbs of oxygen
  - Implication: some units of elements are fundamentally indivisible

Radioactivity

• Radioactivity
• Phosphors flash when hit by radiation
• 1903 demonstrated the twinkling caused by this effect
Brownian Motion

- Brownian motion: erratic, jiggling motion
  - pollen grains suspended in water
- Einstein: motion is random collisions of atoms
  - Predicted particle movement
- Perrin tested and confirmed Einstein’s predictions

X-ray Crystallography

- Developed in 1912
- Demonstrates arrangement of atoms in crystals

Discovering Chemical Elements

- Electrolysis
- Mendeleev
- Current Periodic Table
  - 112 elements
  - 92 found in nature
- Everyday elements
  - Helium, carbon, aluminum, copper, gold

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- Evidence for the atomic particulate nature of matter includes
  - A ratios of elements in chemical combinations
  - B Brownian motion
  - C gas behavior
  - D all of the above

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- Brownian motion is
  - A one of the evidences that matter is atomic
  - B part of the atomic theory
  - C a famous experiment that Albert Einstein and John Dalton worked on together

The Structure of the Atom
The Structure of the Atom

- Thomson identified electron
  - Negatively charged
  - Smaller and lighter than smallest atom
- Atoms are NOT fundamental building blocks, but are made up of smaller more fundamental particles

The Atomic Nucleus

- Rutherford determined atomic structure
- Concluded
  - Atom has nucleus at center surrounded by electrons
- Later discoveries found nucleus is composed of protons and neutrons

Why the Rutherford Atom Couldn’t Work

- Why?
  - Object in circular orbit is accelerating
  - Accelerated electrical charge emits electromagnetic radiation
  - Electrons giving off energy while orbiting
    - Result: Electrons spin toward nucleus eventually atom ceases to exist
  - Rutherford atom exists <1 min

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- Thomson identified a particle called the electron in 1897. This provided evidence that
  - A atoms are not fundamental building blocks of matter
  - B atoms could not be subdivided
  - C atoms are fundamental building blocks of matter

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- The results from Rutherford’s experiment were:
  - A most of the alpha particles scattered and a few alpha particles went straight through the foil
  - B all of the alpha particles scattered
  - C most of the alpha particles went straight through the foil and a few alpha particles scattered

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- The conclusion from Rutherford’s experiment includes the concept that:
  - A atoms have negative particles
  - B atoms are mostly empty space
  - C atoms have high density throughout the atom
When Matter Meets Light

The Bohr Atom

- First working model of atom
- Energy levels for electrons
  - Specific distances from nucleus
  - Electrons exist with no radiation
  - Electrons cannot exist between allowed distances (energy levels)

Example Figure 8-7

Energy changes when level changes

Any level above ground state

Photons: Particles of Light

- Used to move electron to higher energy state
- Photon emitted as electron moves to lower energy state

Photons cont.

- Quantum leap or jump - electron disappears from original location and reappears in final location - never at positions in between

Energy in Bohr atom

- Energy required to leave ground state
  - Absorb photon
  - Heat
  - Increases collisions
Spectroscopy

- Atoms emit and absorb different photons
- Depends on differences between energy levels
- Each atom has distinct set of photons
- Spectrum: all photons emitted by an atom
  - Used for identification

Spectroscopy cont.

Light from gaseous atoms is spread out by passing through a prism

Spectroscopy cont.

Each atom produces a unique set of lines—the atomic fingerprint

<table>
<thead>
<tr>
<th>Atomic hydrogen (H)</th>
<th>Sodium (Na)</th>
<th>Neon (Ne)</th>
</tr>
</thead>
</table>

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- The development of atomic theory from Dalton, Thomson, Rutherford and Bohr shows that:
  - A theories are continually refined as new data becomes available
  - B scientists keep changing their minds
  - C the scientific method does not work

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- In the Bohr model of the atom, a quantum jump is:
  - A when an electron makes a giant leap
  - B when a photon leaps from electron to electron during energy absorbing and emitting processes
  - C when an electron moves from one allowed state to another without ever being in between states

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- The evidence supporting Bohr’s atomic theory (electrons can only be in certain allowed energy levels) is:
  - A atomic line spectra
  - B nuclear radiation emitted by atoms
  - C bombardment of gold foil
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- Spectroscopy is:
  - A another name for lasers
  - B a tool used in almost every branch of science
  - C a device for making eyeglasses

The Periodic Table of the Elements

- Systematizes elements
- Columns contain similar elements
- Soft, silvery elements: all colorless, odorless inert gases

Why the Periodic Table Works: Electron Shells

- Patterns mirror arrangement of electrons in shells
- Pauli exclusion principle
- First shell 2 electrons, second shell 8 etc.

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- The periodic table is arranged with the elements:
  - A getting progressively heavier left to right and top to bottom
  - B having random order
  - C getting progressively more reactive left to right and top to bottom

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- The periodic table "works" because:
  - A of the names of the families of elements (alkali metals, noble gases, etc.)
  - B of the Pauli exclusion principle
  - C the pattern of elements in the periodic table mirrors the spatial arrangement of electrons into shells
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A chemical reaction involves:
- A neutrons in the outermost shell
- B protons in central shells
- C electrons in the innermost shell
- D electrons in the outermost shell

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Which of the following evidences for atoms is most convincing to you:
- A The behavior of gases
- B chemical combinations
- C radioactivity
- D Brownian motion
- E X-ray crystallography

Quantum Mechanics

Chapter 9

Great Idea:
At the subatomic scale, everything is quantized. Any measurement at that scale significantly alters the object being measured.

Chapter Outline

- The World of the Very Small
- Probabilities
- Wave-Particle Duality
- Wave-Particle Duality and the Bohr Atom

The World of the Very Small

- Quantum mechanics
  - Motion of quanta
- Bundles vs. continuous
- Does not match our intuition
Measurement & Observation in the Quantum World

• 3 components to measurement
  – Sample
  – Source of energy
  – Detector
• Quantum World
  – Measurement alters object

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• A quantum leap is when:
  – A an electron leaps from a proton to a neutron
  – B a giant leap is made by some subatomic particle
  – C an electron moves between energy levels and emits a photon

iClicker Questions

• True or False: Everything comes in quantized bundles.
  – A true
  – B false
• Quantum mechanics is the branch of science devoted to the study of:
  – A the Doppler effect
  – B broken electronic devices
  – C imaging devices
  – D the motion of objects that come in small bundles

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• Which three components are essential to every measurement in the physical world?
  – A a sample, a quantum scale and a recorder
  – B a recorder, a detector and a computer
  – C a sample, a detector and a light source
  – D an imaging device, a recorder and a light source
• The fundamental difference between the quantum and macroscopic worlds is:
  – A the objects are too small to detect in the quantum world
  – B the objects are too fast to detect in the quantum world
  – C any measurement at the quantum scale significantly alters the object being measured

The Heisenberg Uncertainty Principle

• Uncertainty Principle:
  – At quantum scale, measurement alters object
• Cannot know position and velocity
• Equation:
  \[ \Delta x \Delta v > \frac{h}{m} \]
• Compare large vs. small objects
  – Small uncertainty with large object
  – Large uncertainty with small object

Probabilities
Probabilities

- **Newtonian View**
  - Determine velocity and position
- **Quantum View**
  - Cannot determine velocity and position
  - Use probability

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- Heisenberg’s equation: \( \Delta x \times \Delta \nu > \frac{\hbar}{m} \), is a shorthand way of saying:
  - A you can never know both the position and velocity of an object with perfect accuracy
  - B you can know both the position and velocity of an object with perfect accuracy if given the mass
  - C you can know both the position and velocity of an object with perfect accuracy if given an accurate value for Planck’s constant

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- We do not have to worry about the uncertainty principle in our everyday life because:
  - A the value of Planck’s constant is very small for large objects
  - B the small velocity of large objects makes the uncertainty principle invalid
  - C for objects with significant mass, the effects of the uncertainty principle are totally negligible
- The uncertainty principle is only significant when applied to:
  - A really large objects such as planets
  - B tiny objects such as protons and electrons
  - C medium objects such as bowling balls

Wave Particle Duality

The Double-Slit Test

- Energy
  - Particles
  - Waves
- Photons
  - Emit photon
  - Flood of photons

Double-Slit cont.

- Single photon over time
- Results depend on experimental design
- Visualizing
  - Not wave or particle
Wave-Particle Duality and the Bohr Atom

- Speed & Wavelength
  - Faster speed = shorter wavelength
- Particle
  - Precise velocity = stable orbit
- Wave
  - Uniform vibration at certain frequencies
- Combine wave & particle?
  - Only orbits allowed are those where both particle and wave work

Wave length determines frequency

Bending wave into circular orbit, fit only certain standing waves into orbit

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- Wave mechanics” is another term for:
  - A people who repair wave generators
  - B study of ocean wave motion
  - C quantum mechanics
- A famous experiment used a double-slit apparatus to determine:
  - A velocity of light
  - B mass of an electron
  - C whether something is a wave or a particle

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- True or False: All quantum objects exhibit properties of both particles and waves.
  - A True
  - B False
- When light strikes one side of a thin sheet of material, electrons can be observed coming out the other. This phenomenon is called:
  - A Einstein’s quantum propulsion
  - B the photoelectric effect
  - C the Heisenberg particle observation

Quantum Weirdness

- Richard Feynmann- “I can safely say that nobody understands quantum mechanics. ...Do not keep saying to yourself, ‘But how can it be like that?’... Nobody knows how it can be like that.”
- Be Careful!
  - Quantum mechanics is still a marvelous and necessary tool for understanding the quantum world

Quantum Entanglement

- Quantum Entanglement
  - Dice
- Photons emitted at same time
  - Despite distance, remain entangled
- Quantum teleportation
  - Is the photon created the same as the one that was destroyed?
• True or False: a group in Vienna sent a picture through the use of quantum teleported photons
  - True
  - False

• Quantum mechanics is being used by some scientists to understand the phenomenon of consciousness. Some have argued that:
  - the brain is no more than a physical structure
  - the workings of the brain can be predicted, but only at the quantum level
  - both a and b

• The idea that quantum objects behave so differently from objects in our everyday experience leads to a feeling that nature has become “weird” at the subatomic level. How does this make you feel?
  - A worried
  - B interested
  - C confused
  - D don’t care