Our goals for learning:
- How do we experience light?
- How do light and matter interact?

5.1 Light in Everyday Life

How do we experience light?
- The warmth of sunlight tells us that light is a form of energy
- We can measure the flow of energy in light in units of watts: 1 watt = 1 joule/s
How do light and matter interact?
- Emission
- Absorption
- Transmission
  - Transparent objects transmit light
  - Opaque objects block (absorb) light
- Reflection or Scattering

What have we learned?
- How do we experience light?
  - Light is a form of energy
  - Light comes in many colors that combine to form white light.
- How does light interact with matter?
  - Matter can emit light, absorb light, transmit light, and reflect (or scatter) light.
  - Interactions between light and matter determine the appearance of everything we see.

5.2 Properties of Light
Our goals for learning:
- What is light?
- What is the electromagnetic spectrum?
What is light?

- Light can act either like a wave or like a particle.
- Particles of light are called **photons**.

Waves

- A wave is a pattern of motion that can carry energy without carrying matter along with it.

Properties of Waves

- **Wavelength** is the distance between two wave peaks.
- **Frequency** is the number of times per second that a wave vibrates up and down.
  
  \[ \text{wave speed} = \text{wavelength} \times \text{frequency} \]
A light wave is a vibration of electric and magnetic fields.

Light interacts with charged particles through these electric and magnetic fields.

Wavelength and Frequency

\[ \text{wavelength} \times \text{frequency} = \text{speed of light} = \text{constant} \]

Particles of Light

- Particles of light are called photons.
- Each photon has a wavelength and a frequency.
- The energy of a photon depends on its frequency.
Wavelength, Frequency, and Energy

\[ \lambda \times f = c \]
\[ \lambda = \text{wavelength} \quad , \quad f = \text{frequency} \]
\[ c = 3.00 \times 10^8 \text{ m/s} = \text{speed of light} \]

\[ E = h \times f = \text{photon energy} \]
\[ h = 6.626 \times 10^{-34} \text{ joule x s} = \text{photon energy} \]

What have we learned?

- What is light?
  - Light can behave like either a wave or a particle
  - A light wave is a vibration of electric and magnetic fields
  - Light waves have a wavelength and a frequency
  - Photons are particles of light.

- What is the electromagnetic spectrum?
  - Human eyes cannot see most forms of light.
  - The entire range of wavelengths of light is known as the electromagnetic spectrum.

5.3 Properties of Matter

Our goals for learning:
- What is the structure of matter?
- What are the phases of matter
- How is energy stored in atoms?
Atomic Terminology

- **Atomic Number** = # of protons in nucleus
- **Atomic Mass Number** = # of protons + neutrons

<table>
<thead>
<tr>
<th>Hydrogen (H)</th>
<th>Helium (He)</th>
<th>Carbon (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>atomic number = 1</td>
<td>atomic number = 2</td>
<td>atomic number = 6</td>
</tr>
<tr>
<td>atomic mass number = 1</td>
<td>atomic mass number = 4</td>
<td>atomic mass number = 12</td>
</tr>
<tr>
<td>(1 electron)</td>
<td>(2 electrons)</td>
<td>(6 electrons)</td>
</tr>
</tbody>
</table>

- Molecules: consist of two or more atoms (H₂O, CO₂)

Atomic Terminology

- **Isotope**: same # of protons but different # of neutrons. (⁴He, ³He)

<table>
<thead>
<tr>
<th>Isotopes of Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon-12</td>
</tr>
<tr>
<td><img src="image" alt="carbon-12" /></td>
</tr>
<tr>
<td>(6 protons + 6 neutrons)</td>
</tr>
</tbody>
</table>

What are the phases of matter?

- **Familiar phases**:
  - Solid (ice)
  - Liquid (water)
  - Gas (water vapor)

- **Phases of same material behave differently because of differences in chemical bonds**
**Phase Changes**

- **Ionization**: Stripping of electrons, changing atoms into plasma
- **Dissociation**: Breaking of molecules into atoms
- **Evaporation**: Breaking of flexible chemical bonds, changing liquid into solid
- **Melting**: Breaking of rigid chemical bonds, changing solid into liquid

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**How is energy stored in atoms?**

- Electrons in atoms are restricted to particular energy levels

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**Energy Level Transitions**

- The only allowed changes in energy are those corresponding to a transition between energy levels
What have we learned?

• What is the structure of matter?
  • Matter is made of atoms, which consist of a nucleus of protons and neutrons surrounded by a cloud of electrons

• What are the phases of matter?
  • Adding heat to a substance changes its phase by breaking chemical bonds.
  • As temperature rises, a substance transforms from a solid to a liquid to a gas, then the molecules can dissociate into atoms
  • Stripping of electrons from atoms (ionization) turns the substance into a plasma

What have we learned?

• How is energy stored in atoms?
  • The energies of electrons in atoms correspond to particular energy levels.
  • Atoms gain and lose energy only in amount corresponding to particular changes in energy levels.

5.4 Learning from Light

Our goals for learning:

• What are the three basic types of spectra?
• How does light tell us what things are made of?
• How does light tell us the temperatures of planets and stars?
• How do we interpret an actual spectrum?
Spectra of astrophysical objects are usually combinations of these three basic types:

- **Continuous Spectrum**: The spectrum of a common (incandescent) light bulb spans all visible wavelengths, without interruption.

- **Emission Line Spectrum**: A thin or low-density cloud of gas emits light only at specific wavelengths that depend on its composition and temperature, producing a spectrum with bright emission lines.

- **Absorption Line Spectrum**:
A cloud of gas between us and a light bulb can absorb light of specific wavelengths, leaving dark absorption lines in the spectrum.

Each type of atom has a unique set of energy levels. Each transition corresponds to a unique photon energy, frequency, and wavelength.

Downward transitions produce a unique pattern of emission lines.
Because those atoms can absorb photons with those same energies, upward transitions produce a pattern of absorption lines at the same wavelengths.

Each type of atom has a unique spectral fingerprint.

Observing the fingerprints in a spectrum tells us which kinds of atoms are present.
Molecules have additional energy levels because they can vibrate and rotate.

The large numbers of vibrational and rotational energy levels can make the spectra of molecules very complicated. Many of these molecular transitions are in the infrared part of the spectrum.

Nearly all large or dense objects emit thermal radiation, including stars, planets, you...

An object's thermal radiation spectrum depends on only one property: its temperature.
Properties of Thermal Radiation

1. Hotter objects emit more light at all frequencies per unit area.
2. Hotter objects emit photons with a higher average energy.

What have we learned?

- What are the three basic types of spectra?
  - Continuous spectrum, emission line spectrum, absorption line spectrum
- How does light tell us what things are made of?
  - Each atom has a unique fingerprint.
  - We can determine which atoms something is made of by looking for their fingerprints in the spectrum.

What have we learned?

- How does light tell us the temperatures of planets and stars?
  - Nearly all large or dense objects emit a continuous spectrum that depends on temperature.
  - The spectrum of that thermal radiation tells us the object's temperature.
- How do we interpret an actual spectrum?
  - By carefully studying the features in a spectrum, we can learn a great deal about the object that created it.
5.5 The Doppler Effect

Our goals for learning:
- How does light tell us the speed of a distant object?
- How does light tell us the rotation rate of an object?

How does light tell us the rotation rate of an object?
- Different Doppler shifts from different sides of a rotating object spread out its spectral lines.

Spectrum of a Rotating Object
- Spectral lines are wider when an object rotates faster.
How does light tell us the speed of a distant object?
- The Doppler effect tells us how fast an object is moving toward or away from us.
- Blueshift: objects moving toward us
- Redshift: objects moving away from us

How does light tell us the rotation rate of an object?
- The width of an object's spectral lines can tell us how fast it is rotating