Chapter 5
Light and Matter: Reading Messages from the Cosmos

5.1 Light in Everyday Life

Our goals for learning:

- How do we experience light?
- How do light and matter interact?

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

Reflection and Scattering

Mirror reflects light in a particular direction

Movie screen scatters light in all directions

Interactions of Light with Matter

Interactions between light and matter determine the appearance of everything around us

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

Interactive Figure

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

wave speed = wavelength x frequency

Light: Electromagnetic Waves

- A light wave is a vibration of electric and magnetic fields
- Light interacts with charged particles through these electric and magnetic fields

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

$$\lambda \times f = c$$

λ = wavelength , f = frequency

$c = 3.00 \times 10^{8}$ m/s = speed of light

$E = h \times f$ = photon energy

$h = 6.626 \times 10^{-34}$ joule x s = 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
- Molecules: consist of two or more atoms (H_2O, CO_2)

Atomic Terminology

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

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

How is energy stored in atoms?

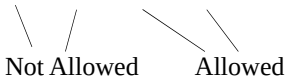
Excited States

Ground State

- Electrons in atoms are restricted to particular energy levels

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?

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

Chemical Fingerprints

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

Energy levels of Hydrogen

Chemical Fingerprints

- Downward transitions produce a unique pattern of emission lines

Chemical Fingerprints

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

Chemical Fingerprints

- Observing the fingerprints in a spectrum tells us which kinds of atoms are present

Energy Levels of Molecules

- Molecules have additional energy levels because they can vibrate and rotate

Energy Levels of Molecules

- 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

Thermal Radiation

- 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.

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.

What have we learned?

- What are the three basic type 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?

Measuring the Shift

Stationary

Moving Away

Away Faster

Moving Toward

Toward Faster

- We generally measure the Doppler Effect from shifts in the wavelengths of spectral lines

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

What have we learned?

- 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