Topics Covered in Chapter

1. Structure of Atoms
2. Origins of Electromagnetic Radiation
3. Objects with Different Temperature and their Electromagnetic Radiation
4. Kirchoff’s Spectral Laws
5. Bohr’s Model of the Atom
6. Doppler Effect

A Subatomic Interlude

A Subatomic Interlude II

A Subatomic Interlude III

A Subatomic Interlude IIII

<table>
<thead>
<tr>
<th>FERMIONS</th>
<th>matter constituents spin = 1/2</th>
<th>Quarks</th>
<th>spin = 1/2</th>
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</thead>
<tbody>
<tr>
<td>Leptons</td>
<td>Flavor</td>
<td>Mass (GeV/c²)</td>
<td>Electric charge</td>
</tr>
<tr>
<td>νe electron</td>
<td>&lt; 7 x 10⁻⁸</td>
<td>0</td>
<td>D bar</td>
</tr>
<tr>
<td>e⁻ electron</td>
<td>0.000051</td>
<td>-1</td>
<td>d</td>
</tr>
<tr>
<td>νe neutrino</td>
<td>&lt; 0.0003</td>
<td>0</td>
<td>e⁺</td>
</tr>
<tr>
<td>μ⁻</td>
<td>0.106</td>
<td>-1</td>
<td>s</td>
</tr>
<tr>
<td>νμ neutrino</td>
<td>&lt; 0.03</td>
<td>0</td>
<td>t</td>
</tr>
<tr>
<td>τ⁻</td>
<td>1.7771</td>
<td>-1</td>
<td>b</td>
</tr>
</tbody>
</table>
A Subatomic Interlude V

- Neutrinos are produced in the “Weak Interaction”, for example
  - Neutrinos from the earth
    - natural radioactivity
  - “Man-made” neutrinos
    - accelerators, nuclear power plants.
  - Astrophysical neutrinos
    - Solar neutrinos
    - Atmospheric neutrinos
    - Relic neutrinos
      - left over from the big bang.

Neutrino Factoids

- The earth receives about 40 billion neutrinos per second per cm$^2$ from the sun.
  - About 100 times that amount are passing through us from the big bang.
    - This works out to about 330 neutrinos in every cm$^3$ of the universe!
    - By comparison there are about 0.0000005 protons per cm$^3$ in the universe.
  - Your own body emits about 340 million neutrinos per day from $^{40}\text{K}$.
  - Neutrinos don’t do much when passing through matter.
    - Thus, it is very difficult to observe neutrinos.

Neutrino Detection

Detecting neutrinos requires a different kind of a detector.

Neutrino Detection II

- Neutrinos are observed by detecting the product of their interaction with matter.

Neutrinos reveal information about the Sun’s core—and have surprises of their own

- Neutrinos emitted in thermonuclear reactions in the Sun’s core were detected, but in smaller numbers ($1/3$) than expected.
- Recent neutrino experiments explain why this is so.
  - Based upon conversion of electron neutrino to tau neutrino.

Determining the Speed of Light

- Galileo tried unsuccessfully to determine the speed of light using an assistant with a lantern on a distant hilltop.
Light travels through empty space at a speed of 300,000 km/s

- In 1676, Danish astronomer Olaus Rømer discovered that the exact time of eclipses of Jupiter’s moons depended on the distance of Jupiter to Earth.
- This happens because it takes varying times for light to travel the varying distance between Earth and Jupiter.
- Using \( d=rt \) with a known distance and a measured time gave the speed (rate) of the light.

In 1850, Fizeau and Foucault also experimented with light by bouncing it off a rotating mirror and measuring time.
- The light returned to its source at a slightly different position because the mirror has moved during the time light was traveling.
- \( d=rt \) again gave \( c \).

Light is electromagnetic radiation and is characterized by its wavelength (\( \lambda \)).

Wavelength and Frequency

Frequency and wavelength of an electromagnetic wave:

\[
\nu = \frac{c}{\lambda}
\]

\( \nu \) = frequency of an electromagnetic wave (in Hz)
\( c \) = speed of light \( = 3 \times 10^8 \text{ m/s} \)
\( \lambda \) = wavelength of the wave (in meters)

The Nature of Light

- In the 1860s, the Scottish mathematician and physicist James Clerk Maxwell succeeded in describing all the basic properties of electricity and magnetism in four equations.
- This mathematical achievement demonstrated that electric and magnetic forces are really two aspects of the same phenomenon, which we now call **electromagnetism**.

Electromagnetism

- **Electricity according to Gauss**
  - relates electricity to electric charge
- **Faraday’s Law**
  - relates electric fields to magnetic fields
- **Magnetism according to Gauss**
  - relates magnetism to electricity
Maxwell’s Equations

• Ampere-Maxwell Law  
  – relates magnetic field to electricity

• Maxwell  
  – unifies electricity and magnetism into electromagnetism

\[ \nabla \times E = \frac{1}{\varepsilon} \rho \]

\[ \nabla \times B = \frac{\partial \mathbf{D}}{\partial t} - \frac{\partial \mathbf{E}}{\partial t} \]

\[ \nabla \cdot B = 0 \]

Because of its electric and magnetic properties, light is also called electromagnetic radiation.

Visible light falls in the 400 to 700 nm range.

Stars, galaxies, and other objects emit light in all wavelengths.

Three Temperature Scales

<table>
<thead>
<tr>
<th>Kelvin</th>
<th>Celsius</th>
<th>Fahrenheit</th>
</tr>
</thead>
<tbody>
<tr>
<td>5800 K</td>
<td>3527 °C</td>
<td>6461 °F</td>
</tr>
<tr>
<td>4622 K</td>
<td>2950 °C</td>
<td>5462 °F</td>
</tr>
<tr>
<td>373 K</td>
<td>0 °C</td>
<td>32 °F</td>
</tr>
<tr>
<td>0 K</td>
<td>-273 °C</td>
<td>-459.67 °F</td>
</tr>
</tbody>
</table>

An opaque object emits electromagnetic radiation according to its temperature.

Wien’s law and the Stefan-Boltzmann law are useful tools for analyzing glowing objects like stars.

- A blackbody is a hypothetical object that is a perfect absorber of electromagnetic radiation at all wavelengths.
- Stars closely approximate the behavior of blackbodies, as do other hot, dense objects.
- The intensities of radiation emitted at various wavelengths by a blackbody at a given temperature are shown by a blackbody curve.
Wien’s Law
\[ \lambda_{\text{max}} = \frac{2.898 \times 10^{-3} \text{ m K}}{T} \]
where \( \lambda_{\text{max}} \) is the wavelength of maximum emission of the object (in meters), and \( T \) is the temperature of the object (in kelvins).

Wien’s law states that the dominant wavelength at which a blackbody emits electromagnetic radiation is inversely proportional to the Kelvin temperature of the object.

Stefan-Boltzmann Law
• The Stefan-Boltzmann law states that a blackbody radiates electromagnetic waves with a total energy flux \( E \) directly proportional to the fourth power of the Kelvin temperature \( T \) of the object:
\[ E = \sigma T^4 \]

Light has properties of both waves and particles
• Newton thought light was in the form of little packets of energy called photons and subsequent experiments with blackbody radiation indicate it has particle-like properties
• Young’s Double-Slit Experiment indicated light behaved as a wave
• Light has a dual personality; it behaves as a stream of particle-like photons, but each photon has wavelike properties

Light, Photons and Planck
• Planck’s law relates the energy of a photon to its frequency or wavelength:
\[ E = \frac{hc}{\lambda} \]
where
- \( E \) = energy of a photon
- \( h \) = Planck’s constant
- \( c \) = speed of light
- \( \lambda \) = wavelength of light
• The value of the constant \( h \) in this equation, called Planck’s constant, has been shown in laboratory experiments to be
\[ h = 6.625 \times 10^{-34} \text{ J s} \]
Prelude to the Bohr Model of the Atom

• The Photoelectric Effect
  – experiment explained by Einstein, but performed by others
  • What caused this strange result?
  • This is what Einstein won the Nobel Prize for

Chemists’ Observations
1. Add a chemical substance to a flame
2. Send light from the flame through a narrow slit, then through a prism
3. Bright lines in the spectrum show that the substance emits light at specific wavelengths only

Each chemical element produces its own unique set of spectral lines

Kirchoff’s Laws

• Any hot body produces a continuous spectrum
  – if it’s hot enough it looks something like this
  – digitally like this

Kirchoff’s First Spectral Law

Kirchoff’s Absorption Spectrum
- Absorption lines are observed when a gas (or solid) absorbs light energy at specific wavelengths, producing dark lines in the spectrum.
Kirchoff’s Second Spectral Law
• Any gas to which energy is applied, either as heat or a high voltage, will produce an emission line spectrum like this
– or digitally like this

Kirchoff’s Third Spectral Law
• Any gas placed between a continuous spectrum source and the observer will produce an absorption line spectrum like this
– or digitally like this

Astronomers’ Observations

An atom consists of a small, dense nucleus surrounded by electrons
• An atom has a small dense nucleus composed of protons and neutrons
• Rutherford’s experiments with alpha particles shot at gold foil helped determine the structure

The atmosphere scatters blue light more effectively than red light—hence mostly blue light reaches your eye when you look at the sky.

(a) Why the sky looks blue

(b) Why the setting Sun looks red
The number of protons in an atom’s nucleus is the **atomic number** for that particular element.

The same element may have different numbers of neutrons in its nucleus.

These slightly different kinds of the same elements are called **isotopes**.

Spectral lines are produced when an electron jumps from one energy level to another within an atom.

- The nucleus of an atom is surrounded by electrons that occupy only certain orbits or energy levels.
- When an electron jumps from one energy level to another, it emits or absorbs a photon of appropriate energy (and hence of a specific wavelength).
- The spectral lines of a particular element correspond to the various electron transitions between energy levels in atoms of that element.
- Bohr’s model of the atom correctly predicts the wavelengths of hydrogen’s spectral lines.

Bohr’s formula for hydrogen wavelengths:

\[
\frac{1}{\lambda} = R \left( \frac{1}{N^2} - \frac{1}{n^2} \right)
\]

- \( N \) = number of inner orbit
- \( n \) = number of outer orbit
- \( R \) = Rydberg constant \((1.097 \times 10^7 \text{ m}^{-1})\)
- \( \lambda \) = wavelength of emitted or absorbed photon
The wavelength of a spectral line is affected by the relative motion between the source and the observer.

Doppler Shifts

- **Red Shift** The object is moving away from the observer.
- **Blue Shift** The object is moving towards the observer.

\[ \Delta \lambda / \lambda_o = v/c \]

\( \Delta \lambda = \) wavelength shift
\( \lambda_o = \) wavelength if source is not moving
\( v = \) velocity of source
\( c = \) speed of light