**QUANTUM PHYSICS**

- **Thermal radiation** → electromagnetic radiation emitted by objects at any temperature.
  - The temperature of the object will determine the wavelength emitted.
  - **Red** stars are lowest temperature stars (app. 3000 K) and emit mostly in the infrared spectrum.
  - **Yellow/White** stars exist at temperatures of about 6000 K (ex: the Sun—5800 K). Most of the emitted radiation is in the visible spectrum.
  - **Blue** stars exist at temperatures of about 12,000 K or more. Emit radiation mostly in the ultraviolet spectrum.

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**Conceptual Example #1**

Betelgeuse is a red-giant star in the constellation Orion. Rigel is a bluish star in the same constellation. Which star has the greater surface temperature? How do you know?

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- Classical physics tells us that as wavelengths of emissions approach zero, the intensity should approach infinity. (I.e., intensity should approach infinity as frequency goes up).
  - Experimental data shows the opposite. It shows that as wavelength approaches zero, so does intensity of the radiation.
- Max Planck (1900) came up with an equation that matched the experimental data.
  - Presumed that these objects could only give off certain discrete amounts of energy.
  - I.e., the energy given off is **quantized**.

\[ E_n = nhf \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Energy</td>
<td>Joules (J)</td>
</tr>
<tr>
<td>h</td>
<td>Planck’s constant</td>
<td>Joules seconds (J∙s)</td>
</tr>
<tr>
<td>f</td>
<td>Frequency</td>
<td>Hertz (Hz)</td>
</tr>
<tr>
<td>n</td>
<td>Quantum number</td>
<td>None</td>
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</tbody>
</table>
- **Planck’s constant**: \( h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s} \)
- \( n \) represents which *quantum state* the object is resonating in.
  - The amount of energy released depends on the quantum state.
  - Can only release energy in these amounts.
  - Energy amounts change in *quantum jumps*.
- It’s like if a pitched baseball could only have a fixed number of different speeds and no speeds in between those fixed values.

**Example Problem #1**

Calculate the energy of the first quantum state for a photon of yellow light with a frequency of \( 5.25 \times 10^{14} \text{ Hz} \).

- Explains the Photoelectric Effect.
- **Photocells** → cells that produce a current in a circuit when light of sufficiently high frequency falls on it.
  - Streetlights flip a switch to turn off the light when the ambient light hits it.
  - Garage doors often have a light beam aimed at a photocell which will be broken if a person/car is standing between the source and the photocell. (Safety precaution—it will cut off the current).

**Dual Nature of Light and Matter**

- 1924 → Louis de Broglie postulated that *because photons have wave and particle characteristics, perhaps all forms of matter have both properties*.
  - Called the **de Broglie wavelength**

\[
\lambda = \frac{h}{p}
\]

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<th>Variable</th>
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<tbody>
<tr>
<td>( \lambda )</td>
<td>Wavelength</td>
<td>Meters (m)</td>
</tr>
<tr>
<td>( h )</td>
<td>Planck’s constant</td>
<td>Joules seconds (J∙s)</td>
</tr>
<tr>
<td>( p )</td>
<td>Momentum</td>
<td>Kilograms meters per second (kg·m/s)</td>
</tr>
</tbody>
</table>

**Conceptual Example #2**

As the momentum of a particle of mass \( m \) increases, its wavelength increases.

True or False?
Example Problem #2

You throw a 0.13 kg apple into the air at 5.0 m/s. What’s its de Broglie wavelength?

- Notice the answer above is tiny. That’s why it really only matters for subatomic particles.

The Uncertainty Principle

- 1927 → Werner Heisenberg proposed his uncertainty principle.
  ➢ **Uncertainty Principle** → It is physically impossible to simultaneously measure the exact position and exact momentum of a particle.
  ➢ I.e., you can’t know both the exact velocity and location of a particle.
  ➢ By observing its position you change its momentum, because photons had to have bounced off the particle in order for you to see it. This changed the velocity of the particle.

![Diagram of electron collision](image)