Energy

- **Kinetic Energy**: energy in the form of motion
  - Individual Motion (e.g., batted baseball)
  - Thermal Energy: energy of particles in random motion

- **Potential Energy**: stored energy
  - Gravitational Potential (e.g., skier at top of slope)
  - Electrostatic Potential (e.g., charged particles)
  - Chemical Potential (e.g., batteries)
  - Rest-mass Energy (nuclear physics)
  - Other types

- **Radiative Energy**
  - Energy in the form of light (photons)
Thermal Energy

- Temperature measures thermal motion

Longer arrows mean higher speed.
Temperature Scales

- 373.15 K (100° C, 212° F) - Water boils
- 273.15 K (0° C, 32° F) - Water freezes
- 0 K (−273.15° C, −459.67° F) - Absolute zero

Kelvin | Celsius | Fahrenheit
Phases of Matter

- Temperature affects the phase of matter
- Temperature of phase shifts depend on the material
Density and Collisions
Structure of the Atom

- Neutral atom has the same number of protons as electrons
Electron Orbits

ground state  excited state  ionization

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## Energy Levels of Atoms

<table>
<thead>
<tr>
<th>Level</th>
<th>Energy Level</th>
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<tbody>
<tr>
<td>ionization</td>
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<tr>
<td>level 4</td>
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<td>12.1 eV</td>
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<tr>
<td>level 2</td>
<td>10.2 eV</td>
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<tr>
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<td>0 eV</td>
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(ground state)
Photons of Light

- The smallest unit of light is a photon
- A photon is often called a particle of light
- The Energy of an individual photon depends on its wavelength (frequency)
- The Energy of a photon is proportional to its frequency:
  \[ E = h \cdot f = \frac{hc}{\lambda} \]
Electromagnetic Spectrum

<table>
<thead>
<tr>
<th>wavelength (meters)</th>
<th>radio</th>
<th>infrared</th>
<th>ultraviolet</th>
<th>X rays</th>
<th>gamma rays</th>
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<table>
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Energy Levels and Spectral Lines
Absorption vs. Emission
Unique Spectral Lines for Atoms

- helium
- sodium
- neon

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Molecular Bands

(a) Rotation

(b) Vibration
Thermal Radiation
Laws of Thermal Radiation

- **Stefan-Boltzmann Law:**
  \[ \frac{L}{A} = \sigma T^4 \]

- **Wien’s Law:**
  \[ \lambda_{\text{max}} T = \text{constant} \]
Spectra in the Lab
Spectrum from Mars

- Emission lines (UV): hot upper atmosphere
- Object reflects red sunlight: rust-colored surface
- CO₂ absorption bands: carbon dioxide atmosphere
- Thermal emission peak in infrared indicates surface temperature about 225 K
Doppler Shift

(a) true wavelength; normal pitch for sound
(b) longer wavelength; sound lower pitched
(c) shorter wavelength; sound higher pitched
Doppler Shift

- $z = \frac{\Delta \lambda}{\lambda} = \frac{v_r}{c}$
- Positive $z$ is a redshift
- Radial velocity is positive moving away
Doppler Shifted Spectral Lines

Laboratory spectrum
Lines at rest wavelengths.

Star 1
Lines redshifted: Star is moving away from us.

Star 2
Greater redshift: Star is moving away faster than Star 1.

Star 3
Lines blueshifted: Star is moving toward us.

Star 4
Greater blueshift: Star is moving toward us faster than Star 3.
Doppler Broadening

A spectral line from star A indicates that star A rotates slowly. Narrow spectral lines indicate that star A rotates slowly. This light is slightly blueshifted.

A spectral line from star B indicates that star B rotates rapidly. Wide spectral lines indicate that star B rotates rapidly. This light is greatly blueshifted.

This light is greatly redshifted.

To Earth, the approaching side is indicated.

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Cloud in Interstellar Space