Metrics and Measurement

Measuring Light and Matter
What do we usually measure?

- Weight
- Height
- Volume
- Distance
- Temperature
The “English” System

mass or weight
  Pounds, ounces, tons
length or distance
  Inches, feet, yards, miles
volume
  Quarts, gallons
temperature
  degrees Fahrenheit
The “Metric” System

- Used everywhere except for:
  - Liberia
  - Myanmar (formerly Burma)
  - United States

- Based on three BASE UNITS

- Powers of Ten system
Metric BASE UNITS

- Length  METER  m
- Mass    GRAM    g
- Volume  LITER   L
- Temperature °Celsius  °C
Important Metric PREFIXES

- Kilo \( k \) \( 1000\times \) or \( 10^3\times \) the base
- Centi \( c \) \( 1/100\times \) or \( 10^{-2}\times \) the base
- Milli \( m \) \( 1/1000\times \) or \( 10^{-3}\times \) the base
- Micro \( \mu \) \( 1/1000000 \) or \( 10^{-6}\times \) the base
- Nano \( n \) \( 1/10000000000 \) or \( 10^{-9}\times \) the base
Why Metrics and Not English?

- Powers of ten can easily represent
  - very large numbers
    \[ 6.02 \times 10^{23} = \text{\# atoms in a mole} \]
  - very small numbers
    \[ 1.0 \times 10^{-7} = \text{\# H}^+ \text{ ions in water} \]
  - Use of logarithms easier
## Measuring EM Radiation

- **Infrared radiation**  
  - Units: micrometers  
  - Value: $10^{-6}$ m

- **Visible radiation**  
  - Units: nanometers  
  - Value: $10^{-9}$ m

- **Ultraviolet radiation**  
  - Units: nm  
  - Value: $10^{-9}$ m

- **X-rays and gamma rays**  
  - Units: Angstrom Å  
  - Value: $10^{-10}$ m
Basic color definitions

Additive Color

Subtractive Color

Your TV

Your paints
Color wheel
Primary, secondary, tertiary?
Complementary, analogous?
Monochromatic Complementary  Analogueous  Triadic
Complementary Colors

Absorbed

Observed
Three Important Regions of EM

- 100% of sunlight is UV - VIS - IR
Three Important Regions of EM

- UV - VIS - IR cause changes in matter
Models or Theories of Light

- **The Wave Theory**
  Explains transmission, reflection and scattering, refraction, diffraction, polarization, and interference of light.

- **The Particle Theory — Planck, Einstein**
  Explains *emission* and *absorption* of light
Particle or Quantum Theory

- What’s the relationship between energy \( (E) \), frequency \( (\nu) \), and wavelength \( (\lambda) \) of light?

\[
E = h \nu = \frac{hc}{\lambda}
\]

- \( h \) = Planck’s constant

Light is composed of a stream of packets of energy called **Quanta** or **Photons**.
Emission of Light

- Emission spectrum of Helium gas

- Energy of blue light
- Energy of yellow light
- Energy of green light
Absorption of Light by Matter

- Absorption spectrum of Sodium gas

- Dark lines = light energy absorbed
Interaction of Light With Matter

- Absorbed
- Refracted
- Reflected or Scattered
- Transmitted

Light

Absorbed

Reflected or Scattered

Transmitted

matter

Refracted
Seven Types of Matter

Transparent and colorless
Transparent and colored

Translucent and colorless
Translucent and colored

Opaque and white

Opaque and black
Opaque and colored
Absorption and Transmission

White light — composed of all wavelengths

White opaque object transmits all wavelengths

Black opaque object absorbs all wavelengths.

Colored opaque objects selectively absorb and transmit (or reflect) light.
Absorption of Light by Matter

- Matter consists of **atoms** and **molecules**
- Atoms contain **electrons**
- Molecules contain **chemical bonds** which form by exchange or sharing of electrons between atoms
- Light interacts with matter through electrons
Measuring Light Absorption

Single Beam Spectrophotometer
Laws of Light Absorption

- \( I_o \) = intensity of light through blank
- \( I_T \) = intensity of light through sample
- Absorption = \( I_o - I_T \)
- Transmittance = \( I_T/I_o \)
- Absorbance = \( \log(I_o/I_T) \)
Laws of Light Absorption

- Lambert’s Law

Light 80% of Light

Thicker matter absorbs more light

Light 64% of Light
Laws of Light Absorption

- Beer’s Law

Absorption depends upon concentration of absorbing matter
Absorbance & Beer’s Law

Increasing absorbance
Laws of Light Absorption

- Beer-Lambert Law
  \[ A = abc \]
  
  - \( A \) = absorption
  - \( b \) = path length (thickness of matter)
  - \( c \) = concentration of matter
  - \( a \) = absorptivity constant (fudge factor)
Beers Law: \[ A = abc \]

What is the relationship between Absorption (A) and concentration (c)?

1. As “c” gets smaller “A” gets bigger.
2. As “c” gets larger “A” gets larger.
3. There is no relationship.
4. As “A” gets smaller “c” gets bigger.
Spectral Curves

Transmission Curve

%T vs $\lambda$

Absorption Curve

$A$ vs $\lambda$

Can be used to help identify colored matter
Measuring Light Absorption

Qualitative analysis...

- Plot absorbance or %transmittance versus wavelength to get spectral curves
Measuring Light Absorption

Quantitative analysis…

- Green colored Chlorophyll leaf extract
- 4 chlorophyll standard solutions

<table>
<thead>
<tr>
<th>Concentrations</th>
<th>Absorbances (A)</th>
</tr>
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<tbody>
<tr>
<td>5%</td>
<td>0.100</td>
</tr>
<tr>
<td>10%</td>
<td>0.200</td>
</tr>
<tr>
<td>15%</td>
<td>0.300</td>
</tr>
<tr>
<td>20%</td>
<td>0.400</td>
</tr>
</tbody>
</table>

- Unknown chlorophyll solution $A = 0.250$
Graphing the Data

Beer's Law Plot

Concentration (percent)

Absorption

0.125 = 12.5%