Lecture # 3

Light

(Review of Plant Physiology)
What Is Light?

Light is electromagnetic radiation, emitted when an electrical dipole (a paired positive and negative charge, separated by a small distance) in an atom oscillates and causes change in the field of force. The dipole produces an electrical and a magnetic vector, which are in phase but at right angles. Fluctuations in the field strength of these vectors are perpendicular to the direction of travel of the wave, and hence, light is a transverse wave.
FIGURE 8.1. Light is a transverse electromagnetic wave, consisting of oscillating electric and magnetic fields that are perpendicular to each other and also perpendicular to the direction of propagation of the light. Light moves at a speed of $3 \times 10^8$ m s$^{-1}$. The wavelength ($\lambda$) is the distance between successive crests of the wave.
The electromagnetic wave is characterized by both wavelength, $\lambda$ which is the distance between successive positive or negative maxima on the sine wave, and by frequency, $\nu$, the number of oscillations per unit time. Wavelength and frequency are related by the velocity of propagation of the wave, $v$: 

$$v = \lambda \nu$$
The Dual Nature of Light

Wave - wavelength, frequency, velocity.

Particle - “photon”; each photon contains an amount of energy - quantum (pl. quanta).

The energy content of light is delivered in discrete units, quanta. The photon has no rest mass.

Quantum and photon are distinct concepts!
Quantum is the energy carried by a photon!
**Characteristics of Light**

The energy of a photon ($\varepsilon$) depends on the frequency of the electromagnetic wave, which is related to $\lambda$:

$$\varepsilon = h \nu = \frac{h \nu}{\lambda}, \quad h = \text{Planck's constant}$$

The greater the frequency, and the smaller the wavelength, the larger the energy of the photon.

1 mole contains as many elementary particles as there are carbon atoms in 0.012 kg of $^{12}\text{C}$, or Avogadro’s number, $6.023 \times 10^{23}$, of particles.

1 mole photons (mole of quanta) = 1 Einstein = $6.023 \times 10^{23}$
A plant exposed to far red light grows fast - in height.

Once it is past that other green fellow it expands its green umbrella to revise its strategy for absorbing energy.

Lars Bjorn

Question: In what two basic ways does the plant use light?
Ways a Plant Can Perceive Light

- Light Quantity (photon counting).
- Light Quality (photon ratios).
- Light Duration (timing light / dark transitions).
- Light Direction (photon gradients).
- Light Polarization (dichroic photoreceptor).
Ways a Plant Can Perceive Light

TERMS:
- Photosynthesis
- Photoperiodism
- Photomorphogenesis
- Phototropism
- Phototaxis
Light Terminology

- **Photosynthesis**: “making something using light”; continual input of energy is required.
- **Photoperiodism**: A nondirectional response to a nondirectional **periodic** stimulus.
- **Photomorphogenesis**: A nondirectional developmental response to a nondirectional **nonperiodic** stimulus.
**Light Terminology**

- *Phototropism*: A directional growth response to a directional stimulus.
- *Phototaxis*: A directional movement to a nondirectional periodic stimulus.
Measurements of Light

- Physical.
  Measuring the energy of light.
  Energy - J, cal, erg, ev (electron volts)
  Power - energy/time
  Irradiance - energy/time/per unit space (area, volume)
Measurements of Light

- Psychophysical.
  Measuring the energy of light but tailored to fit the human eye.
  Ft-c, lumens, lux (metric term) - all are intensity terms.
  Brightness - measures reflection from a surface.
Measurements of Light

- Phytophysical.
  Measuring the light detected by a plant. Photosynthesis; Photomorphogenetic processes
**Measurements of Light**

- **Phytophysical:**
  - Photon Irradiance (400-700nm) - $\mu$mol m$^{-2}$s$^{-1}$
  - Photon Fluence Rate (2$\pi$ or 4$\pi$ sensor)

![](image)
Plant Response

- Plant maintenance:
  The minimum photosynthetic irradiance for a foliage plant is that which permits the plant to function at a level slightly exceeding the compensation point at which photosynthesis is equal to respiration.
  - Native habitat
  - Production irradiance levels
  - Degree of acclimatization.
Questions to Ponder

1. What is Light Compensation Point (LCP) ?
2. What is CO$_2$ Compensation Point ?
3. How are the LCP and CO$_2$ CP related ?
4. Which is more likely to perform better in interior environment - C$_3$, C$_4$, CAM, or C$_3$ - C$_4$ type of carbon fixation mechanism ?
CO₂ Assimilation (μmol CO₂ m⁻² s⁻¹)

Photosynthetically active radiation (μmol quanta m⁻² s⁻¹)

5. Study carefully the graph. (question follows)
5. Question:
   The $CO_2$ assimilation curves were obtained in a normal atmosphere (21% $O_2$). How would the two curves ($C_3$ and $C_4$) change if the same experiment was conducted in an atmosphere containing only 1% $O_2$?
Light and Photosynthesis in the Intact Leaf

FIGURE 10.1. Conversion of solar energy into carbohydrates by a leaf. Of the total incident energy, only 5% is converted into carbohydrates.
Only about 5% of the solar radiation reaching the earth can be converted into carbohydrates by a photosynthesizing leaf. This is because a major fraction of the incident light is of wavelengths too short or too long to be absorbed by the photosynthetic pigments.
The Plant Leaf - An Overview of Structure
Palisade mesophyll cells: one to three layers of columnar cells; they allow light to pass through.

Spongy mesophyll cells: several layers of irregularly shaped cells; they trap light passing from the palisade layer.
The Architecture and Composition of a Leaf

Maximize Light Absorption

- Sieve effect: due to the fact that the chlorophyll is not uniformly distributed in the cells but is confined to the chloroplasts. This clustering of chloroplasts results in shading between the chlorophyll molecules, so that the total absorption of light by a given amount of chlorophyll in a chloroplast is less than that of the same amount in a solution.
The Architecture and Composition of a Leaf

Maximize Light Absorption

- Light guide effect: channeling of some of the incident light through the intercellular spaces between the palisade cells, in a manner analogous to transmission of light by an optical fiber.
The Photosynthetic Response to Light in the Leaf Reflects Basic Properties of the Photosynthetic Apparatus

Light Compensation Point:
The photosynthetic irradiance at which the net CO$_2$ exchange in the leaf is zero. At this point the amount of CO$_2$ evolved by mitochondrial respiration is balanced by the amount of CO$_2$ fixed by photosynthesis.

LCP for sun plants: - 10 - 20 μmol m$^{-2}$ s$^{-1}$
LCP for shade plants: - 1 - 5 μmol m$^{-2}$ s$^{-1}$
The Photosynthetic Response to Light in the Leaf Reflects Basic Properties of the Photosynthetic Apparatus

- **Carbon Dioxide Compensation Point:**
  The $CO_2$ concentration at which $CO_2$ assimilation is zero.
  At this point $CO_2$ fixation by photosynthesis balances $CO_2$ loss by respiration.
The $CO_2$ Compensation Point reflects the balance between photosynthesis and respiration as a function of $CO_2$ concentration, and the Light Compensation Point reflects such a balance as a function of photosynthetic irradiance.
The relationship between photosynthesis and respiration in the daily cycle of a plant.

- **Compensation Point**
  - Rate of respiration equals rate of photosynthesis

- **Photosynthesis exceeds respiration:**
  - Food stored

- **Respiration exceeds photosynthesis:**
  - Food used up

The relationship between photosynthesis and respiration in the daily cycle of a plant.
Relative Light Intensity

Light Saturation point

More photosynthesis than respiration

Light Compensation Point

Relative Light Intensity (Increasing)

More respiration than photosynthesis

Net gas exchange

High CO₂ evolution in darkness

High CO₂ uptake