Light and Waves
Light

It is part of the electromagnetic spectrum, which consists of radiation from radio waves all the way to X-rays and gamma rays.

The visible portion of the spectrum is only a small part of the spectrum.

All electromagnetic radiation moves at the same speed, the speed of light.

\[ c = 3 \times 10^8 \text{ m/sec} \]

This speed is the speed in a vacuum.

In any other medium, such as a gas or a liquid, the speed of light is less.
Cerenkov Radiation

In a medium, such as glass or water, it is possible for particles to travel faster than the reduced speed of light

This results in radiation being emitted by the particle – Cerenkov Radiation

Often seen in reactor pools
Electromagnetic Spectrum
Characteristics of a wave

Besides the speed of a wave, there are two other parameters of importance. These are:

- **Wavelength** – $\lambda$
  
  This is the distance from one peak to the next

- **Frequency** – $f$
  
  This is the number of peaks passing a given point in one second

These two quantities are related to the speed in the following way:

$$v = \lambda f$$

With $v$ being the wave speed.
Wave Motion

Wave motion consists of two distinct motions:

1) Motion of the wave form from one point to another

2) Motion of the medium in which the wave is moving
Wave Types

Two different types of waves

Transverse Waves
Here the motion of the medium is perpendicular to the motion of the wave form
Examples: Water waves, waves on string

Longitudinal Waves
Here the motion of the medium is parallel to the motion of the wave form
Example is a sound wave
Light as Electromagnetic Wave

Light consists of both electric and magnetic fields

The electric and magnetic fields are perpendicular to each other
History of Light

The Greeks
  Light was a particle which entered the eye

Became fashionable to treat light as a wave

Galileo tried to measure its speed but could not

Newton
  Light was a particle. Correctly described reflection and refraction
  Predicted that light should travel faster in a medium – never tested
  Light in fact travels slower in a medium
History of Light

Young
Light was a wave
Used wave properties to explain interference phenomena

Maxwell
Predicted existence of electromagnetic waves with the prediction for the speed of these waves matching that of light
History of Light

Hertz

- Found the predicted waves
- Also saw phenomena known as the photoelectric effect that could not be explained

Einstein

- Explained photoelectric effect based on a particle picture for electromagnetic radiation

Light is both a wave and a particle

Which interpretation you use is dependent upon the type of experiment you are doing
Blackbody Radiation Spectrum

All objects emit and absorb energy (radiation)
  How much is determined by its temperature
  How fast is determined by the temperature of its surroundings

As an object heats up, its color changes from a deep red to being blue-white

Talk in terms of an ideal object - a blackbody

A blackbody is a perfect absorber and a perfect emitter
Blackbody Radiation Spectrum

Experimentally it is found that the energy that is emitted is a function of the wavelength and the exact shape of the curve is temperature dependent.

As the temperature increases:
- Total energy emitted increases – area under curve
- Wavelength of peak emission decreases
Blackbody Radiation Spectrum

The radiation emitted by a black body has a definite shape, which is known as the blackbody spectrum.

Many physicists attempted to derive this curve using classical wave theory.

In classical wave theory the energy content of a wave is related to the amplitude squared.

Using this assumption, all attempts were unsuccessful.

This was often referred to as the ultra-violet catastrophe, since the theoretical curve would rise to infinity at short wavelengths.
Blackbody Radiation Spectrum

Max Planck built on the work of Einstein.

Energy content of an electromagnetic wave was proportional to its frequency or inversely proportional to the wavelength.

\[ E = hf \text{ or } E = h \left( \frac{c}{\lambda} \right) \]

With this assumption Planck successfully described the blackbody curve.
Blackbody Radiation Spectrum

Several important relationships have been found experimentally. These also can be derived from Planck's work.

Stefan's Law:

The total radiation emitted from a blackbody goes up as the fourth power of the absolute temperature.

\[ E = \sigma T^4 \]

Wien's Law:

As the temperature of an object increases, the wavelength at which the most energy is emitted decreases.

\[ \lambda_{\text{max}} = \frac{0.29}{T} \]
Photons

The other important assumption in the work of Planck and Einstein was that all of this energy is contained within a small packet and not distributed as it is in a wave.

This packet then being called a photon
Kirchoff’s Laws

Radiation from a blackbody is continuous, that is all wavelengths are emitted – a continuous spectrum

Pass continuous radiation through a cool gas and observe radiation on the opposite side
  Transmitted radiation is no longer continuous, there are missing wavelengths. Certain wavelengths "absorbed" – an absorption spectrum

View gas cloud at an off angle. Only certain wavelengths appear. Certain wavelengths are being emitted – an emission spectrum
Kirchoff’s Laws
Elemental Signatures

All elements have a unique emission spectrum
What is the origin of these emission lines?
These lines are discrete
Only certain wavelengths

Matter was known to be made up of atoms, which was thought to be the smallest building block

Atom was known to contain both positive and negative particles
Not understood as to exactly how the atom was structured
Elemental Signatures

(a)

(b)

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Structure of the Atom

Various schemes, such as plum pudding model, put forth as to how and why atoms radiated only at certain wavelengths.

None were successful in correctly predicting the wavelengths of the emitted radiation.
Structure of the Atom

Ernest Rutherford showed, from experimental data, that the atom was not amorphous as some had thought.

He proposed that the atom had a small, hard core that contained most of the mass and that this core, the nucleus, was positively charged.

The negative charges, that were known to exist, then orbited this nucleus.

However, according to classical theory, this atom would be unstable as far as size goes.
Structure of the Atom

Classical theory predicts that in such a model, the electrons orbiting the nucleus should spiral inwards towards the nucleus in a very short time.

This is known not to happen.

Is the model wrong, or could it be the theory?
Bohr’s Postulates

Neils Bohr stated that our theoretical understanding was at fault. Classical theory did not apply.

Bohr came up with three postulates. These are that:

1) The atom is stable
2) The electrons could only be in certain orbits corresponding to unique energies - This is quantization
3) The radiation emitted from an atom is due to the electron making a transition between allowed levels
4) The energy of the emitted radiation is equal to the difference in energies of the two levels involved
Bohr’ Model

Based on these postulates, Bohr derived both the energies of the radiation emitted from the hydrogen atom and the size of the hydrogen atom.

The correct theory of the structure of the atom and its functioning did not come about until the advent of quantum mechanics.
Spectra

An atom gains energy by the absorption of a photon
This causes the electron to move to a higher orbit
The energy of the photon must match the energy difference between the two levels
This is known as excitation
If the energy is large enough the electron will be ejected from the atom
This is known as ionization

An atom emits radiation when an electron makes a transition to lower energy level
The energy of the emitted photon is equal to the energy difference between the two levels.

This model of the atom leads to a straightforward understanding of Kirchoff's Laws
Atomic Spectra

Every atom has a unique spectrum
The lines in the spectrum of an atom are also discrete, only certain wavelengths are present
Careful examination of the spectra received by telescopes, reveals which elements are present in the object being studied

Examination of the spectrum also can yield information concerning the relative motion of the object being studied
This information comes from the Doppler effect
Doppler Effect

The Doppler Effect is the apparent shifting of the observed wavelengths

This occurs when the source and/or the receiver is in relative motion

When the source and receiver are approaching each other, the apparent wavelength of the emitted radiation is shorter
  For visible light, this means a shifting towards the blue end of the spectrum - A blueshift

When the source and receiver are departing from each other, the apparent wavelength of the emitted radiation is longer
  For visible light, this means a shifting towards the red end of the spectrum - A redshift