Photons: Note for UPSC

The photon is a variety of elementary particle. It is the quantum of the electromagnetic field including electromagnetic radiation such as light and radio waves and the force carrier for the electromagnetic force.

Origins of the concept of Photons

The present-day theory of the photon was conceived by Albert Einstein in the early 20th century to explain experimental observations that did not fit the classical wave model of light. The benefit of the photon model is that it accounts for the frequency dependence of light's energy, and explains the ability of matter and electromagnetic radiation to be in thermal equilibrium.

The photon model accounts for anomalous observations, including the properties of black-body radiation, that others had tried to explain using semiclassical models.

Properties of a Photon

A photon is massless, has no electric charge, and is a stable particle. A photon has two possible polarization states. In the momentum representation of the photon, which is preferred in quantum field theory, a photon is described by its wave vector, which determines its wavelength λ and its direction of propagation. A photon's wave vector may not be zero and can be represented either as a spatial 3-vector or as a (relativistic) four-vector. Different signs of the four-vector denote different circular polarizations, but in the 3-vector representation one should account for the polarization state separately; it actually is a spin quantum number. In both cases the space of possible wave vectors is three-dimensional.

Like all elementary particles, photons are currently best explained by quantum mechanics and exhibit wave-particle duality, exhibiting properties of both waves and particles. For example, a single photon may be refracted by a lens and exhibit wave interference with itself, and it can behave as a particle with definite and finite measurable position or momentum, though not both at the same time as per Heisenberg's uncertainty principle. The photon's wave and quantum qualities are two observable aspects of a single phenomenon—they cannot be described by any mechanical model a representation of this dual property of light that assumes certain points on the wavefront to be the seat of the energy, is not possible.

Photons are emitted in many natural processes. For example, when a charge is accelerated it emits synchrotron radiation. During a molecular, atomic or nuclear transition to a lower energy level, photons of various energy will be emitted, ranging from radio waves to gamma rays. Photons can also be emitted when a particle and its corresponding antiparticle are annihilated (for example, electron-positron annihilation).

A brief overview of the properties of a photon is given below:

Properties of a Photon	
Charge	+1.60 x 10^{-19} C
Relative Charge	+1
Mass	1.672 x 10^{-24} g
Relative Mass	1 amu
Location	Nucleus

Technological Applications

Photons have multiple applications in technology. These examples are chosen to illustrate applications of photons but rather than general optical devices such as lenses, etc. that could operate under a classical theory of light. The laser is an extremely important application and is discussed above under stimulated emission.

Individual photons can be detected by several methods. The classic photomultiplier tube exploits the photoelectric effect: a photon of sufficient energy strikes a metal plate and knocks free an electron, initiating an ever-amplifying avalanche of electrons. Semiconductor charge-coupled device chips use a similar effect: an incident photon generates a charge on a microscopic capacitor that can be detected. Other detectors such as Geiger counters use the ability of photons to ionize gas molecules contained in the device, causing a detectable change of conductivity of the gas.

Because of the high X-ray and neutron intensities provided by large-scale facilities, short exposure times and extraordinary statistics are possible, leading to a large amount of valuable data. High-energy X-rays, such as provided by modern synchrotron radiation sources, bear the advantage of high photon brilliance and low absorption in most materials, enabling time-resolved in situ measurements in transmission geometry of bulk materials of several millimetres in thickness.