339(5): Compton Scattering by Vacuum Particles

In the simplest theory, a hypothetically massless photon is scattered by a vacuum particle with mass, resulting in a change in frequency of the photon. This is considered to be a cosmological process, so light propagating through billions of light years of deep space is repeatedly affected by collisions with vacuum particles of mass $m(\text{vac})$. The equation of conservation of energy is:

$$\hbar\omega + m(\text{vac})c^2 = \hbar\omega' + \left(m^2(\text{vac})c^4 + c^2 p'^2(\text{vac})\right)^{1/2} \quad -(1)$$

This describes a hypothetically massless photon of energy $\hbar\omega$ colliding elastically with a static vacuum particle of mass $m(\text{vac})$. The photon is scattered with energy $\hbar\omega'$ and the vacuum particle is given the momentum $\underline{p}'(\text{vac})$.

The equation of conservation of momentum is:

$$\hbar\underline{\kappa} = \underline{p}' + \hbar\underline{\kappa}' \quad -(2)$$

where $\hbar\underline{\kappa}$ is the momentum of the incoming photon and $\hbar\underline{\kappa}'$ is the momentum of the scattered photon.

The theory exactly parallels the Compton scattering of a photon from a static electron - the latter is situated in a metal foil. Solving eqns. (1) and (2) leads to:

$$\frac{1}{\omega'} - \frac{1}{\omega} = \frac{\hbar}{m(\text{vac})c^2}(1-\cos\theta) \quad -(3)$$

) as in UFT158 ff. The angle θ is defined by:

$$(\underline{\kappa}-\underline{\kappa}')\cdot(\underline{\kappa}-\underline{\kappa}') = \kappa^2+\kappa'^2-2\kappa\kappa'\cos\theta \quad -(4)$$

The direction of the momentum of the photon is changed by the collision with the vacuum particle.

Over billions of light years of propagation, the direction is changed by countless collisions, so the relevant ensemble statistics have to be used to calculate the overall change in frequency:

$$\left\langle \frac{1}{\omega'}-\frac{1}{\omega}\right\rangle = \frac{\hbar}{m(\text{vac})c^2}\langle(1-\cos\theta)\rangle \quad -(5)$$

As in UFT309 there is a cosmological red shift so the above Compton theory can be used with the Beer Lambert law. Finally the light becomes diffuse by countless collisions with vacuum particles, and this is analogous to the diffusion of light by the atmosphere in Rayleigh scattering.

So these topics can be developed in the next notes.