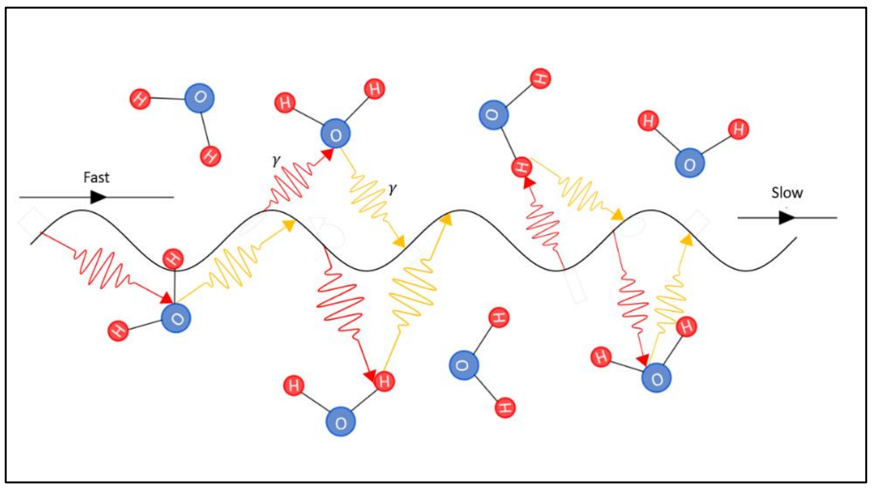
Amarvir Chana

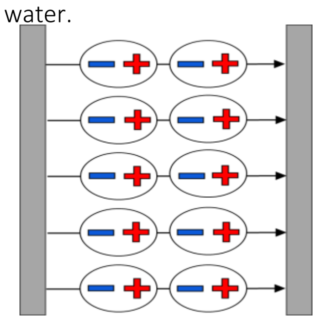
Cerenkov Radiation – How to travel Faster than Light

Introduction



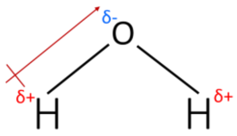
- Since a lot of radiation or fluorescence is green, red, orange or yellow, I've generally wondered whether a blue variant could exist. Upon researching this I discovered Cerenkov Radiation, which not only causes a blue glow but creates this from shockwaves when going faster than light. Yes, faster than light. So I decided to research what it is, how it works and what its used for.
- When light travels through a physical medium, that medium will have an optical density and so the light will travel slower. This speed can be calculated using the refractive index, n.
- This doesn't tell us why light slows down, however there's an explanation of this according to the classical theory of light acting as a wave:
- As light travels through an optically dense medium, like water, instead of propagating through unhindered at 3×10^8 ms^{-1}, the photons actually get absorbed by electrons in the water and then re-emitted near instantaneously, creating a slight delay.
- The electrons absorb the photons because light is a disturbance in the EM- field, which charged particles such as electrons interact with, and so they become excited as their field is disturbed.
- Think of it as the light being a large splash in a pool and the electron as a swan. The swan will be disturbed by the ripples from the splash and perhaps bob up and down.
- Because there are massive numbers of electrons in water, this process happens so many times that all these delays add up, slowing light to ¾ of its speed in water.

Cerenkov Radiation

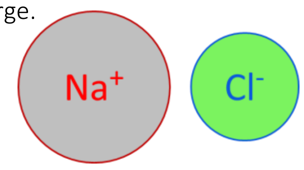


A polarized dielectric medium

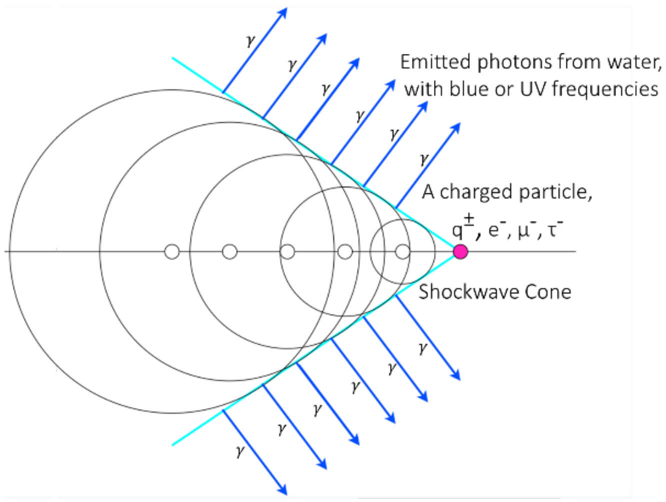
- Light travels at 0.75C ms^{-1} in water but electrons have the same speed as they would in air, 0.977C ms^{-1}, so technically, electrons can swim faster than light.
- This radiation occurs when a charged particle travels through a dielectric medium faster than the phase velocity of light in that medium. This is usually water
- A dielectric medium is anything that is a poor electrical conductor but can support electrostatic fields and store charge.



Examples include many solid ionic salts, water and even the vacuum.

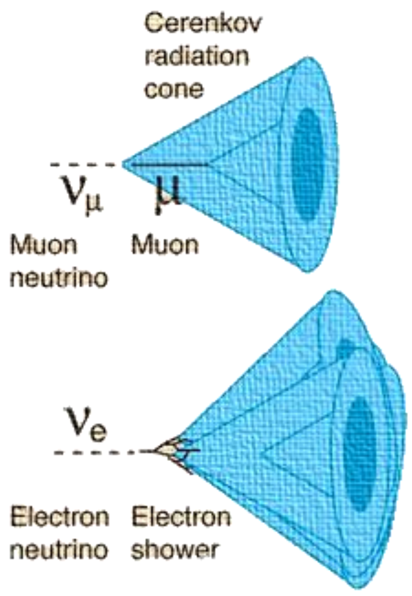


- This form of radiation was observed by Marie Curie in 1910, when noticing a pale blue light coming from a radium solution.
- As the electron propagates through, it will continually interact with some water molecules, causing them to emit high energy photons of light in spheres that still travel slower than the electron. These photons will have a much a higher frequency than light from standard forms of fluorescence, being the blue to UV part of the EM spectrum
- These high energy photons will bunch up behind the electron, forming a shockwave cone.
- In water the shockwave tends to be bright blue in the visible spectrum and is observed in nuclear reactors or particle colliders.

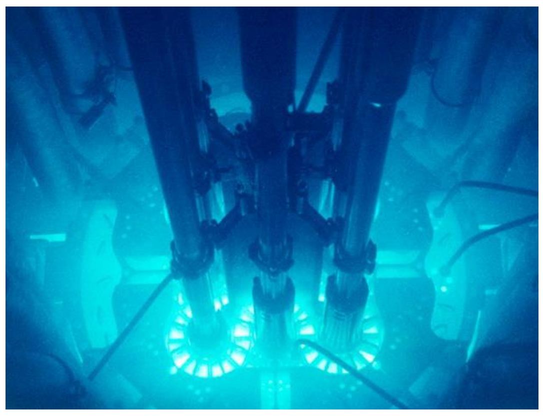


Applications

- Used in detecting neutrinos – from neutrino collisions that cause electron emission.
- Distinguishing between electron and muon emissions – The muon will have a single shockwave cone, leaving a well defined circle on a detector.
  - An electron will produce of a shower of electrons, each with their own shockwave cone, leaving a diffuse circle on the detector.
- Measuring the speed and direction of charged particles from cosmic rays.
- The largest Detector that utilises the properties of Cerenkov radiation is the Super-Kamiokande detector in Japan. This detector can be used to detect when a lepton neutrino (ν_e, ν_μ) converts into its corresponding lepton (e, μ) and creates a shockwave cone.



- This is an example of the Cerenkov Radiation from an underwater 'swimming pool' nuclear reactor in Idaho, USA known as the advanced test reactor.

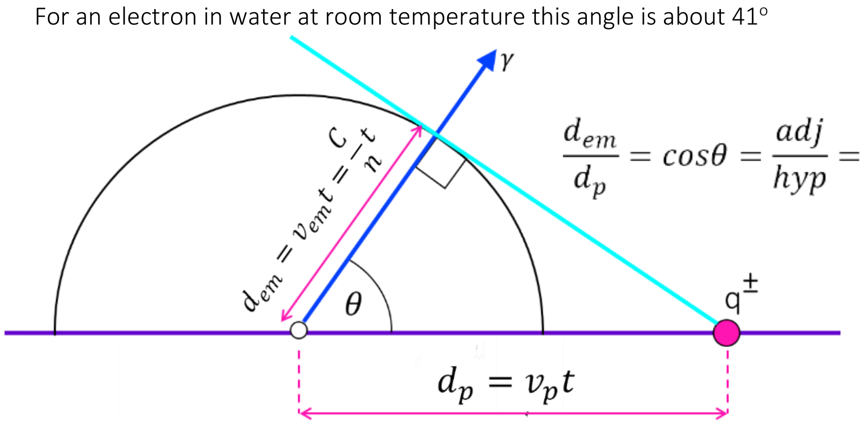


Formulae

- Consider a charged particle moving through water faster than the phase velocity of light in water: $n_{water=}$ 1.33. The velocities of the particle and light would obey the following inequality and have a ratio, beta:

$$\frac{C}{n} < v_p < C \qquad \beta = \frac{v_p}{C}$$

- So, as the charged particle moves through a distance d_p, the emitted Cerenkov light will cover a distance d_{em}.
- Therefore, we can calculate the cone angle θ and the greater the value of θ, the faster the particle is moving relative to light.
- For an electron in water at room temperature this angle is about 41°



$$\frac{d_{em}}{d_p} = cos\theta = \frac{adj}{hyp} = \frac{C}{nv_p}$$

- From this information, we can calculate the velocity of the charged particle

$$v_p = \frac{C}{n\cos\theta}$$

- We can also find its energy using $E=mc^2$, and the Lorentz transformation, γ, which describes the energy of particles moving slower than light in a vacuum

$$E_{particle} = \gamma mc^2 = \frac{1}{\sqrt{1-\frac{v_p{}^2}{C^2}}}mc^2$$

- Now assuming we have a situation where an electron is travelling faster than light in water with a shockwave cone angle of 41°, we can calculate its energy:

$$\cos\theta = \frac{1}{n\beta}$$

$$\theta = 41^{\circ}$$

$$n_{water} = 1.33$$

$$\beta = \frac{1}{n\cos\theta}$$

$$m_e = 9.0109\times10^{-31}kg$$

$$E_{electron} = \gamma m_e c^2 = \frac{1}{\sqrt{1-\beta^2}}m_e c^2 = \frac{1}{\sqrt{1-\frac{1}{n^2\cos^2\theta}}}m_e c^2 = 9.463\times10^{-13}J = 5.9\,MeV$$

This is over 10 times the rest energy of an electron!