Cherenkov radiation

Spent fuel pool

HESS telescopes

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\[
\left( \frac{dE}{dx} \right) = q^2 \int_{n(\omega) > \beta^{-1}} d\omega \ \omega \left[ 1 - \frac{1}{\beta^2 n^2(\omega)} \right]
\]
Introduction

- Cherenkov effect:
  - Radiation appears, when fast charged particles fly through a medium
  - ED analogy to the supersonic flight in Hydrodynamics
Historical events

- First experimentally discovered and described in 1934 by Pavel Cherenkov and his supervisor Sergei Wawilow
- Theoretical description by Ilja Frank and Igor Tamm in 1937
- All historical papers unfortunately in Russian
Historical events

Nobel prize in 1958 for Tamm, Cherenkov and Frank „for the discovery and interpretation of the Cherenkov effect.“
Creation

- Charged particles cross a medium

Important quantities:

- Particle velocity $\beta$
- Index of refraction $n^2 = \varepsilon_r$
- Phase velocity of light $c_n = n^{-1}$

- Cherenkov radiation can only be observed at $\beta > c_n$
Creation

- Every charged particle polarizes the medium
- Excited medium radiates spherical waves

Left: Relaxation of the elementary waves and no wavefront
Right: Elementary waves build up to form a wavefront

\[ \beta < c_n \quad \beta > c_n \]
Creation

Cherenkov angle $\theta_c$:

$$\cos(\theta_c) = \frac{c_n}{\beta} = \frac{1}{\beta n}$$
Spectrum

Frank-Tamm formula

\[
\frac{d^2 N}{d\omega dx} = q^2 \left( \frac{\mu}{4\pi} \right) \sin^2(\theta_c)
\]

N: # of Cherenkov photons
q: charge of the particle
\(\mu\): permeability
\(\theta_c\): Cherenkov angle
Index of refraction $n$

- Optical material property
- Describes phase velocity of light
- Frequency dependent (dispersion)
- For high frequencies (x-ray): $n<1$
Spectrum

Final Cherenkov spectrum:

\[
\left( \frac{dE}{dx} \right) = q^2 \int_{n(\omega) > \beta^{-1}} d\omega \, \omega \left[ 1 - \frac{1}{\beta^2 n^2(\omega)} \right] \left( \frac{\mu(\omega)}{4\pi} \right)
\]
Applications

- Gamma-ray astronomy
  - First programs in 1989
  - HESS Project (Namibia)
  - $\gamma$-rays create charged secondary particles
  - Cherenkov-light is detected
Applications

- Neutrino research
  - Same idea as before
  - $\nu$ react with water/ice and produce muons
  - IceCube in Antarctica uses $1 \text{ km}^3$ of ice
  - Kamiokande in Japan with 50,000 t water
Applications

- Spent fuel pools
  - Spent nuclear fuel is stored in water pools
  - Characteristic blue shining due to Cherenkov
  - Intensity proportional to nuclear decay

spentfuelpool.com
Sources

- Bolotovskii, Frenkel: „I. Tamm Selected Papers“
  - Tamm, Frank:
    „Coherent Visible Radiation of fast Electrons Passing Through Matter“
- Landau, Lifschitz: Elektrodynamik der Kontinua
- Jackson: Klassische Elektrodynamik
- Wikipedia.org
Thank you for your attention!