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P4_5 The Relativistic Ionisation Speed Limit

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Abstract

The paper explores a possible speed limit to be enforced on relativistic vehicles so as to not expose pedestrians to ionising electromagnetic radiation; a result of Doppler shifted light from the vehicle's headlights. A maximum speed limit of 2.89×10^8 ms^{-1}, 0.96 times the speed of light, was established.

Introduction

Ionising radiation poses a significant risk to organic matter through the breaking of chemical bonds. Up to 10% of cancers are induced by ionising radiation exposure [1]. All electromagnetic radiation with frequencies higher than upper ultraviolet radiation is classified as ionising.

When a source of electromagnetic radiation moves relative to an observer, a phenomenon called the Doppler Effect acts to change the wavelength of the observed radiation. For sources moving towards the observer the wavelength is observed at a smaller value than it is emitted. This change in wavelength increases with increasing relative velocity, therefore it is possible for emitted non-ionising optical radiation to be observed as ionising ultraviolet (and above) radiation.

This paper calculates a theoretical speed limit that relativistic vehicles such as spaceships must obey so as to not irradiate passing space-pedestrians with the headlights on the vehicle's front. The velocity required to Doppler shift the headlights into ionising radiation is likely relativistic as this phenomenon is not significantly obvious at vehicle velocities common on Earth.

Ionising Radiation

Ionising radiation is categorized by the type of particle that makes up the radiation; this paper focuses on electromagnetic radiation which is carried by the photon. Photons are classified as ionising when they have enough energy to liberate an electron from an atom via the photoelectric effect. They are considered as indirectly ionising as they themselves are neutrally charged, but the released charged electron can go on to ionize many other atoms.

Due to an ionized molecule's instability, they quickly undergo chemical changes which, in organic matter, can lead to the mutation of a cell's DNA. This mutation can lead to the death of a cell, or begin the development of cancer [2]. Ionising radiation can also cause other health conditions such as radiation burns, and acute/chronic radiation syndrome. It is therefore important to take precaution to limit human exposure to ionising radiation.

To find out a wavelength of radiation which could be considered as ionising to a human, we must look at the electron binding energies of the most common elements in the body. Hydrogen, Oxygen and Carbon make 93.7% of a human body's mass [3], and have an initial ionising energy of 13.598 eV, 13.618 eV and 11.260 eV respectively [4]. Therefore using E_T = 13.618 eV = 2.179×10^{-18} J as the threshold energy and the equation

$$\lambda_T = \frac{hc}{E_T}, \qquad \text{(Equation 1)}$$

where h is Planck's constant and c is the speed of light, results in a minimum wavelength of λ_T = 9.13×10^{-8} m. This wavelength is in the extreme ultraviolet section of the electromagnetic spectrum, and will be the limit imposed to decide the maximum speed limit.

Relativistic Doppler Effect

The equation for the relativistic Doppler shift changes depending on the relative direction of

motion of the vehicle with respect to the pedestrian. To allow the use of the simple equation, we assume the pedestrian is stood alongside the vehicles trajectory (much like the path alongside a road), and is an object at infinity, so the direction of motion can be assumed to be along the line of sight. The equation used for this situation is

$$\frac{\lambda_O}{\lambda_E} = \sqrt{\frac{1-\frac{v}{c}}{1+\frac{v}{c}}}, \qquad \text{(Equation 2)}$$

where λ_O is the observed wavelength, λ_E is the emitted wavelength and v is the velocity of the vehicle. As the vehicle approaches the pedestrian, the observed wavelength increases (becomes less "blueshifted") until it equals the emitted wavelength (at the point of closest approach to the pedestrian). After which, as the car moves away, the observed wavelength further increases to a wavelength larger than its emitted wavelength, and is said to be "redshifted".

Headlight Wavelength

Tungsten-halogen lamps are commonly used as the light-source in vehicle headlights. They do not emit a singular wavelength, but instead have a power spectrum as seen in Figure 1, which peaks at 656.28 nm [6].

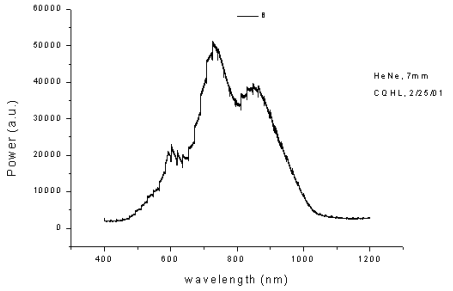

Figure 1 - Power spectrum for a halogen lamp. [6]

Halogen lamps with a high temperature filament do already emit at the ultraviolet wavelengths. But they are often combined with an ultraviolet-absorbing glass filter thereby increasing exposure safety [7]. However, despite this ultraviolet filter, the emitted light can still be observed as ultraviolet when the vehicle is at high velocities.

Speed Limit

By taking the emitted wavelength λ_E as the peak of the halogen lamp spectrum, 6.56×10^{-7} m, and the observed wavelength λ_O as 9.13×10^{-8} m we can find the speed limit for the vehicle. Through rearranging Equation 2 for velocity, the maximum speed before the headlights expose the pedestrian to ionising radiation is $v = 2.89 \times 10^8$ ms^{-1}. This value is 0.96 times the speed of light.

Discussion

Due to the nature of Doppler shifting, the only other alternatives to enforcing a speed limit to ensure the safety of the pedestrian are either for them to wear an ultraviolet-absorbing filter, or for the filter on the lamp to absorb larger wavelengths. However, each of these precautions would only further raise the maximum speed limit; therefore there is no apparent substitute to a speed limit.

Conclusion

The maximum speed limit for a relativistic vehicle found to be 2.89×10^8 ms^{-1}, 0.96 times the speed of light. This highly relativistic speed limit allows a large amount of freedom to drivers that wish to travel relativistically without exceeding this limit. However, any attempt to further raise the speed limit may pose a challenge to ensure no pedestrians are exposed to ionising radiation.

References

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