# Electromagnetic Radiation Redshifts with Propagation Distance in the Presence of Obstacles

Edward Conway[1]

**Abstract**

This paper applies Landauer's principle to show that in the presence of obstacles, destructively observed electromagnetic radiation must redshift with propagation distance in order to obey energy conservation.

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## 1. EM Radiation Redshifts with Propagation Distance in the Presence of Obstacles

Consider a photon traveling from a source at A to an observer at B where the path of the photon is blocked by an obstacle with probability $p \in (0, 1)$. Suppose the photon begins its journey with energy $E_A$ at A and ends its journey at B with energy $E_B$. When the photon arrives at B, its arrival embodies the information that there was nothing blocking the photon on its journey from A to B. The photon is thus carrying $b = -\log_2(1-p) > 0$ bits of information.

The act of observation at B destroys the photon and erases the $b$ bits of information it was carrying[3]. By Landauer's principle [1], the erasure of $b$ bits of information requires an amount of energy $E_b = bkT \log 2$, where $k$ is the Boltzmann constant and $T$ is temperature.

For conservation of energy we require that $E_A = E_B + E_b$ and so the photon's observed frequency must change by $\Delta f$ with

$$\Delta f = \frac{E_B - E_A}{h} = -\frac{E_b}{h} = \frac{kT}{h} \log(1-p), \tag{1}$$

where $h$ is Planck's constant. Electromagnetic radiation therefore appears to have redshifted when observed after traveling through space with an uncertain chance of interception by an obstacle.

Let $d$ be the distance between A and B which reside in a larger homogeneous space. The probability of a blockage over any distance $nd$ where $n \in N^+$ is then $1 - (1-p)^n$ and the information content in bits of a photon on arrival after traveling a distance $nd$ becomes $-n \log_2(1-p)$. So redshift increases with total distance $D = nd$ as follows:

$$\Delta f \quad = \quad D \cdot \frac{kT}{hd} \log(1-p). \tag{2}$$

In terms of wavelength, where $f$ and $\lambda$ are the original frequency and wavelength respectively at A, and $c$ is the speed of light, this becomes

$$\frac{\Delta\lambda}{\lambda} = \frac{-\Delta f}{f + \Delta f} = \frac{-D\lambda kT \log(1-p)}{chd + D\lambda kT \log(1-p)}. \tag{3}$$

[1] Independent scholar orcid.org/0000-0001-5501-0677
*Email address:* `redshift@edwardconway.co.uk` (Edward Conway)

[3] Unless the information content of this specific photon is accurately recorded.

## 2. Cosmological Implications

Assume an unbounded, flat, non-expanding, homogeneous universe. If we consider a single photon emitted with original wavelength $\lambda$, then at the limit of visibility where $R_\lambda$ is the radius of the visible universe at wavelength $\lambda$, all the energy of the photon is spent on the information erasure $E_b$ giving

$$hf = E_b = -R_\lambda \cdot \frac{kT}{d} \log(1-p). \tag{4}$$

Substituting this into equation (3) gives

$$\frac{\Delta\lambda}{\lambda} = \frac{D}{R_\lambda - D}, \tag{5}$$

which shows how redshift tends to infinity as distance approaches the limit of the visible universe.

## 3. Further Research

It may be possible to verify these results by laboratory or field experiment. Additionally, the reshaping of spectra implied by equation (3) and the differential limits of visibility by wavelength could be compared with empirical observations. Non-destructive observation or the logging of individual photon information may permit $R_\lambda = \infty$.

## References


[1] R. Landauer, Irreversibility and heat generation in the computing process, IBM journal of research and development 5 (3) (1961) 183–191.