However, this is in contrast to the results obtained for a similar type of cell sensitized with natural pigment cyanin (extracted from pomegranate fruits). $TiO_2$|cyanin|CuI cell produces higher photocurrent under illumination of a tungsten filament bulb (Tungsraflex R60, 100W) than under AM 1.5 conditions[11]. Proper spectral matching of the tungsten lamp with that of $TiO_2$|cyanin|CuI cell could be a reason. We have studied photo-properties of the cell by replacing the CuI layer by CuCNS. $TiO_2$|mercurochrome|CuCNS cell produces a lower photocurrent compared to that of the cell with CuI, at any visible wavelength (curve b, Figure 2). This may be due to high resistivity of the CuCNS film. The current–voltage characteristics of $TiO_2$|mercurochrome|CuCNS cell (AM 1.5 conditions) are also shown in Figure 3 (curve c). $TiO_2$|mercurochrome|CuCNS cell produces an open circuit voltage of 720 mV and short circuit photocurrent of 1.0 mAcm$^{-2}$. The slightly higher conduction band position of CuCNS (compared to CuI) favours higher open circuit voltage as observed. However, we did not observe any significant change in the current–voltage properties when $TiO_2$|mercurochrome|CuCNS cell is irradiated with the 100 W tungsten filament lamp. This type of solar cell exhibits a slow degradation of less than 5% per day in the dark and much faster degradation under illumination[12]. The stability of $TiO_2$|mercurochrome|CuI solid-state cell was studied under prolonged illumination. A decay in the photocurrent was observed with a rate of 20% per day. We have again deposited CuI on the cell after it had degraded nearly completely (~ 90%). During this treatment, a drop of CuI suspension was deposited on the cell, while the back contact was removed. A rise in the photocurrent was observed. The maximum photocurrent obtained was ~ 30% less than that under first illumination. Formation of new bonds between CuI and dyed $TiO_2$ grains is believed to be the reason for regeneration of the cell. Recently, more extended stability was achieved by covering $TiO_2$ grains with a thin ZnO layer for these type of cells[13]. Confinement of electrons in $TiO_2$ grains covered by a thin ZnO layer could be a reason for the extended stability. Therefore, a break-up of the bridge between CuI and dyed-$TiO_2$ grains could be one of the reasons for degradation of the cell.

In conclusion, formation of aggregates and their equilibrium with monomers resulted in broadening of the absorption of mercurochrome–$TiO_2$ coupled system. An efficient electron transfer process is observed between two solid phases (CuI and $TiO_2$). Solid-state $TiO_2$|mercurochrome|CuI cell produces an open circuit voltage of 490 mV and short circuit photocurrent of 5.5 mA cm$^{-2}$, with reasonably high conversion efficiency. The performance of the cell could be further improved by understanding the bridge between CuI and $TiO_2$.

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# Gravity-induced negative refraction of electromagnetic waves

The conventional description of electromagnetic refraction at the interface between two isotropic, homogeneous, dielectric–magnetic medium, as presented in standard textbooks on optics, is that of *positive* refraction. A defining characteristic of positive refraction is that the phase velocity and the power flow are co-directional in the refracting medium. Accordingly, materials which support this conventional form of planewave propagation are positive-phase-velocity (PPV) materials. In contrast, under exceptional circumstances which do not readily arise for naturally occurring materials, the phase velocity can be directed opposite to the direction of power flow. Thereby, *negative* refraction can occur. Materials which support this anomalous form of planewave propagation are called negative-phase-velocity (NPV) materials[1].

Within the past five years, pioneering work by experimentalists and theoreticians has resulted in successful fabrication of effectively homogeneous metamaterials which support negative refraction in the microwave frequency regime[2]. This has generated a great deal of interest in the electromagnetics and optics research communities. Current efforts are directed towards high infrared frequencies, with the ultimate aim being optical negative refraction. The interest in NPV metamaterials has been fuelled by the groundbreaking technological possibilities they offer. Among these, the prospect of nearperfect lenses made from planar slabs of NPV metamaterials has attracted particular attention[3].

A quite different perspective on negative refraction is provided via the relative motion of inertial reference frames, courtesy of the special theory of relativity[4]. A material which is PPV when viewed from the perspective of an inertial reference frame $\Sigma$ can be NPV with respect to an inertial reference frame $\Sigma'$ which is translating at a sufficiently high velocity relative to $\Sigma$. The velocities required to bring about NPV propagation in a material which is PPV at rest are unlikely to be readily encountered in terrestrial scenarios, but are more likely to be found in astronomical scenarios.

Recent investigations on NPV propagation within the context of the general theory of relativity have revealed intriguing opportunities for negative refraction in vacuum, with possible far-reaching consequences for observational and theoretical astronomy and space exploration[5]. Planewave propagation in gravitationally affected vacuum may be conveniently studied though exploiting a formal analogy between vacuum in curved spacetime and a fictitious bianisotropic medium in flat spacetime, as described by Igor Tamm[6]. This analogy enables the gravitational influence on vacuum to be represented through the constitutive parameters of the bianisotropic medium. As compared to isotropic dielectric–magnetic mediums, the bianisotropic mediums present considerably broader scope for NPV propagation through their much larger constitutive parameter space[7]. The precise nature of the bianisotropic medium is dictated by the metric of the underlying curved spacetime[8]. NPV propagation in gravitationally affected vacuum has been explored for the following two particular types of spacetime metric.

The first is the spacetime associated with a rotating black hole, known as Kerr spacetime. NPV propagation is supported inside, but not outside, the ergosphere of a rotating black hole[9]. Furthermore, within the ergosphere, NPV propagation is more prevalent (a) away from the polar regions and (b) at higher black-hole angular velocities. NPV propagation must be distinguished from super-radiant scattering in the ergosphere[10]. Both phenomenons involve negative energy densities but there are two important differences:

(i) In black-hole super-radiance, negative energies arise from photons with angular momentum initially oriented in the opposite sense to the black-hole rotation. In contrast, the angular momentum of NPV plane waves can be oriented in both the opposite and the same sense as the black-hole rotation.

(ii) The frequency of waves which can undergo super-radiance is bounded. In contrast, NPV propagation occurs at wavelengths which are short relative to the radius of spacetime curvature, but there is no upper bound on frequency.

The second is the spacetime associated with a positive (negative)-valued cosmological constant $\Lambda$, known as de Sitter (anti-de Sitter) spacetime[11]. Whereas anti-de Sitter spacetime has been found not to support NPV propagation, de Sitter spacetime does support NPV propagation for sufficiently high values of $\Lambda$. Thus, the possibility of an NPV-based experiment to distinguish between de Sitter and anti-de Sitter spacetimes emerges. Notably, for de Sitter spacetime within the vicinity of a nonrotating black hole, NPV propagation arises at lower values of $\Lambda$ than is the case for de Sitter spacetime alone[12].

Electromagnetic radiation from distant stars passes through many different regions of gravitationally affected spacetime before reaching our telescopes on Earth. Therefore, the possibilities of gravity-induced negative refraction add further complexities to the challenge of estimating stellar locations. In addition, gravity-induced negative refraction may play an important role in addressing fundamental theoretical issues, such as those relating to the expansion of the universe and the characterization of dark matter.

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