A Reflecting Polarizer as a Quantum Watchdog

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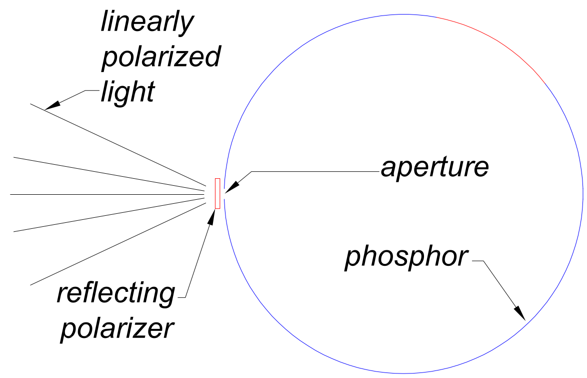
1 Problem

Discuss how a reflecting polarizer[1] at the output slit of a fluorescent aperture lamp[2], as sketched below, acts as a kind of quantum watchdog[3] [4]-[12] which drives the full power of the randomly polarized light produced inside the lamp into a polarized output beam by repeated interaction with photons of the "wrong" polarization.[4]



An aperture lamp is a variant of a fluorescent bulb in which the phosphor extends over only a portion of the azimuth of the cylindrical glass housing. Phosphor molecules are excited by ultraviolet light emitted during the steady electrical discharge of the low-pressure gas inside the lamp, and subsequently de-excite via emission of visible light with random polarization. Some of this light is absorbed and re-emitted by the phosphor. In this problem, assume that there are no losses in this absorption/re-emission.

[1] Planar reflecting polarizers, based on nanofabrication, are a relatively recent development. See, for example, [1]. The technical motivation seems to have been for bright LCD displays for laptop computers.

[2] The phosphors are typically metal oxides with a PO_4 radical, often with rare-earth elements. The first variant of an aperture lamp may be from 1936 [2].

[3] The notion of a quantum watchdog was anticipated by Alan Turing shortly before his death in 1954, as recorded on p. 7 of a letter that year by his student R.O. Gandy to R.H.A. Newman [3]: *A slightly more serious contribution to quantum mechanics was "The Turing Paradox"; It is easy to show using standard theory that if a system starts in an eigenstate of some observable, and measurements are made of that observable N times a second, then, even if the state is not a stationary one, the probability that the system will be in the same state after, say, 1 second, tends to one as N tends to infinity; i.e., that continual observation will prevent motion. Alan and I tackled one or two theoretical physicists with this, and they rather pooh-poohed it by saying that continual observation is not possible. But there is nothing in the standard books (e.g., Dirac's) to this effect, so that at least the paradox shows up an inadequacy of Quantum Theory as usually presented.*

[4] This procedure was suggested in Figs. 2 and 9 of [1], and in Fig. 9 of [13].

2 Solution

If only one polarization of the output light is desired, a polarizer could be put at the aperture of the lamp. Ordinarily, this would eliminate half of the otherwise unpolarized light. However, if a reflecting polarizer is used, light of the undesired polarization is reflected back into the lamp, and becomes unpolarized (*i.e.*, randomly polarized) again upon diffuse reflection by the phosphor. When this light (re)emerges through the aperture, half of it adds to the output of the desired polarization, and half is sent back into the lamp, *etc.* If there are no losses in this process, eventually all of the light emerges with the desired polarization, whose brightness is thereby twice that of the output light of the desired polarization in the absence of the reflecting polarizer (or if a more ordinary polarizer were used which did not recycle the light of the undesired polarization).

In Hamiltonian optics [14] it is not be possible to convert unpolarized light into light of a single polarization, with all light in the same area in phase space [15] (called the étendue in optics[5] and emittance in particle-beam dynamics[6]) as the unpolarized light. In the present example, the key is that light of the "wrong" polarization is reflected back onto the phosphor, which re-emits it with a different, random polarization (and random direction), such that the rejected light is "measured" again and again by the reflecting polarizer until it is transmitted with the "right" polarization. The process of light being directed back to its source to be absorbed and re-emitted has been called light recycling (in [1, 13, 21] and elsewhere). The conversion of unpolarized light by the combination of "measurement" by a reflective polarizer and randomization by diffuse reflection/light recycling is an example of the quantum watchdog effect [12] (aka the Turing paradox of footnote 3 above, aka the quantum Zeno effect [8]).

An even more dramatic result of light recycling is that the brightness of the phosphor surface (and of the output of the lamp) is enhanced N-fold by the re-emission of each photon N times, where in the absence of the reflecting polarizer N is approximately the ratio of the azimuthal extent of the phosphor to that of the aperture [22].

Thanks to Scott Zimmerman for introducing the author to this problem.

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http://kirkmcd.princeton.edu/examples/patents/ouderkirk_EP0736188_polarizer.pdf

[2] C. Birdseye, *Reflecting Glow Lamp*, US Patent 2,135,480 (filed Aug. 26, 1936),
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[5] The more complete French technical term is l'étendue géométrique du faisceau, the geometric extent of beams. The French word étendue (area, extent, range) may have first appeared in English technical literature in the English abstract of the French paper [16], and next in sec. E of the review [17] which also may be the first application of Liouville's theorem [18] to optics. Use of the name étendue was discouraged in [19] and is not common except in the literature of light concentrators.

[6] The concept of emittance as pertaining to particle beams seems to have been invented in 1952 by Sigurgeirsson [20], who called it "admittance" in his eq. (22).

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