

The Michelson Interferometer and the Conservation of Energy

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1 Introduction

In this brief essay, we consider an idealized Michelson interferometer whose elements are perfectly placed as to give beams that are precisely orthogonal or parallel. (See Figure 1.) With such an apparatus, it is in principle possible to adjust the mirror distances as to give completely destructive interference at the detector. Hence, we are presumably forced to conclude that our simple interferometer violates the conservation of energy. While the source is pumping light energy into our system, the light is apparently nowhere to be found.

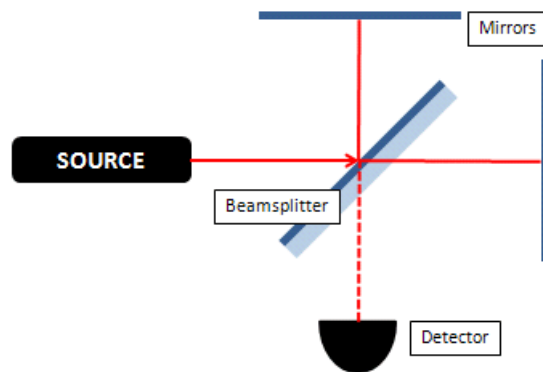


Figure 1: The beamsplitter-mirror distances of an idealized Michelson interferometer can be configured as to give completely destructive output (i.e. no light) at the detector.

We argue that this conclusion is false. As is the usual with such “disappearance of energy” paradoxes, we will show that there is an alternative output channel for light energy. Furthermore, according to basic electromagnetic theory, we find that this secondary channel must receive maximal light intensity precisely when there is destructive interference at the primary detector.

2 Secondary channel

The beamsplitter takes an incident beam, and produces reflected and transmitted beams of equal energy. Obviously, this is how the light is initially split towards the two mirrors. Then, in an exactly the same way, the reflected beams from the mirrors must be split upon *their* striking the beamsplitter. Therefore, it is easy to see that there is a secondary channel for light output: rather than towards the detector, light can be sent directly back to the source!

3 Complementarity of the two channels

We have now identified a potential location of the missing energy. The remaining task is to show, from the equations of electromagnetism, that if the light is not at the detector, then it must be headed towards the source.

In particular, recall that on dielectric reflection, there is a phase shift of π in the reflected beam when the second medium is optically denser than the initial medium. Otherwise, there is no phase shift in reflection. There is never a phase shift in transmission.

In Figure 2 is the beamsplitter of the interferometer in greater detail. The dark blue region represents the reflective surface and the light blue is the dielectric substrate

whose index of refraction is greater than that of air. I have used green and red to show the parentage of each beams.

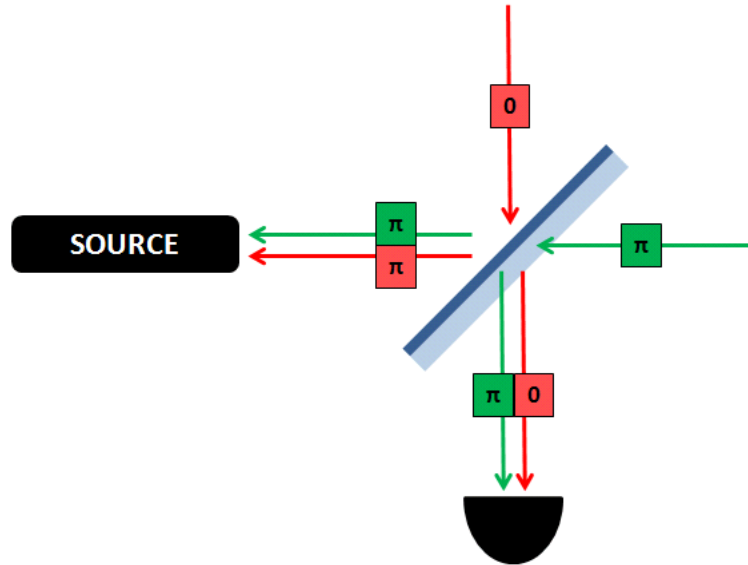


Figure 2: Assuming destructive interference at the detector, we use the phase shift rules to find the relative phase for the beams headed towards the source. The boxed quantities represent the phase gained from reflections and transmissions.

Since there is complete destructive interference at the detector, the two beams have relative phase of π . We can arbitrarily set the phase of the red beam to zero. Then, we deduce backwards: since the original green beam underwent reflection in a dense-to-light medium transition, the green parent beam has equal phase π . Similarly, the red beam was transmitted, so the original red beam has phase of 0.

Finally, we propagate the beams towards the source. The green beam suffers no extra phase shift since it is transmitted. On the other hand, the red beam reflects off of a denser medium, so it gains an extra phase of π . We conclude: a π relative phase at the detector leads to identical phase at the source. Hence, the two channels are indeed complementary and light energy is *not* disappearing in our interferometer.