Introduction to the Hanbury Brown and Twiss effect

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In science, it is often the case that newly unearthed phenomena become controversial between different scientists and researchers. Moreover, it sometimes takes time for novel methods to find uses in which they can be utilized properly and proficiently. The Hanbury Brown and Twiss (HBT [1]) effect is no exception. It possesses a colourful history due to the prevailing understanding of electromagnetism and quantum mechanics at the time of its discovery. Furthermore, the HBT effect has found new applications even rather recently, although it has already been recognized for over a half-century. The aim of this essay is to give an introduction to the effect. For one to be able to apprehend the effect and fully appreciate its complexities, a brief glance into its history is required.

At the turn of the 1950s, Robert Hanbury Brown was on a mission to measure the angular sizes of stars. He was using two radio dishes pointed at the target object and examining the interference patterns of the two signals. There was a problem, however: the dishes needed to be extremely far away from each other for the system to function – too far for the experiment to be feasibly conducted. Luckily though, Hanbury had an epiphany. He noticed a similarity between the noise patterns from the two signals when the radio dishes were positioned close to one another. This was in fact a correlation in the signals; one that would disappear if the distance between the dishes sufficiently increased. Such correlations are known today as the HBT effect. Hanbury constructed a system which exploited this very phenomenon and which could be used to gauge the sizes of celestial bodies. He called the device an intensity interferometer, for it specifically compared the intensities of two signals. As it turned out, however, the technique was not as effective or necessary for radio astronomy as Hanbury had hoped, but it would soon find more appropriate uses [1].

One new and closely related application for the HBT effect proved to be optical astronomy. With the help of mathematician Richard Twiss, Hanbury concluded that the effect should also arise with light visible to the human eye, not just radio waves. Many others in the scientific community disagreed however, which was primarily due to the current view of the nature of electromagnetic radiation at different wavelengths [1]. The contention was eventually resolved with the help of other scientists [1] after Hanbury and Twiss conducted a small-scale experiment [2] which used a mercury-vapour lamp, a thermal source like a star. A beam of light from the lamp was directed into a partially transparent mirror that split the beam into two. The separated beams would then arrive at separate detectors. The setup was still the same in principle because comparing the separated beams was equivalent to comparing two different points in the thermal source [3]. The experiment was successful, and Hanbury eventually went on to apply the method in measuring the angular size of Sirius [4]. These achievements vitally contributed to the acceptance of the theory of the effect.

The HBT effect is relatively easy to comprehend in a classical view, in which light is interpreted as a wave. For example in the above-mentioned mercury lamp experiment, the mirror lets some of the light through and reflects the rest, effectively splitting the light in two. If the two detectors are at an equal distance from the mirror, the split waves will reach the detectors simultaneously, thus explaining the correlation. Likewise, if the difference between the two distances is small enough, a correlation will still be observed. The correlation will only disappear with a greater difference in the distances and thus a greater time difference in the detections.

When it comes to quantum mechanics, the HBT effect is significantly more challenging to grasp even though the mathematics behind the effect are essentially the same. In a quantum mechanical view, light consists of photons which cannot be split in half in the same sense as a classical wave. A single photon will either pass through the mirror or reflect off it, with some probability[1]. Since there still exists a correlation within the signals of the two beams, the only explanation is that the photons tend to arrive at the detectors in quick succession, in bursts. The phenomenon, currently referred to as photon bunching, has since been extensively researched [5]. It is now clear that the effect does not exclusively concern photons, but other bosons as well. An inverse effect, conveniently named anti-bunching, also exists, but it can generally only be observed with fermions. These bunching and anti-bunching effects are explained by the quantum mechanical nature of bosons and fermions [6], and they are the foundation upon which many of the current applications of the HBT effect are built.

Although the first notable application of the HBT effect was measuring the sizes of celestial objects, it currently has many implementations in various fields. Firstly, the discovery of the effect led to the creation of a completely new branch of physics, quantum optics [3], [6], [7]. Furthermore, the HBT effect can be utilized in atomic and condensed matter physics [3], [8]. Its suitability for studying the scattering of light in quasi-homogeneous media has also been researched [8].

The HBT effect describes intensity correlations between two particle beams. At its core, the phenomenon is simpler than it might seem at first glance – at least explaining it has become more straightforward as our understanding of the world has improved over the decades. Hence, it is completely understandable that the effect and its implications were not immediately accepted in unison in the 1950s. It is through these kinds of complications and debates, however, that science keeps advancing. One might even dare say that they are vital to its development.

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[1] It would be more precise to say that the photon's location is in a superposition of both possible routes. Most importantly though, the photon will only be detected at one of the detectors.

References

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