Interaction-Free Measurements

Learning To See In The Dark

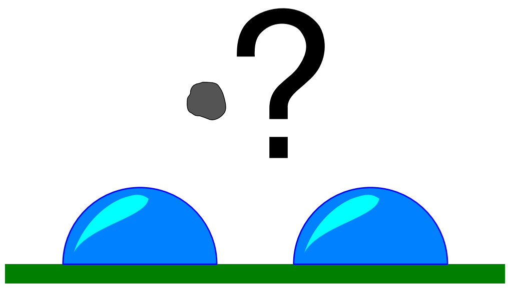
‘No observation can be made without at least one photon striking the observed object.’
Dennis Gabor (1962)

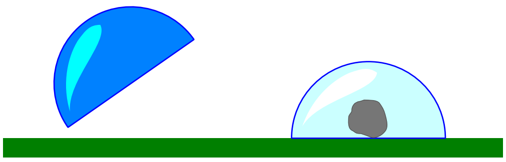
This is NOT true.

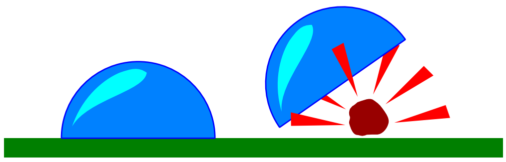
Quantum optics allows us to determine the presence of an object with essentially no photons having touched it.

The Shell Game

Hidden under one of the shells is a highly volatile pebble.
To win you must find the pebble without destroying it.







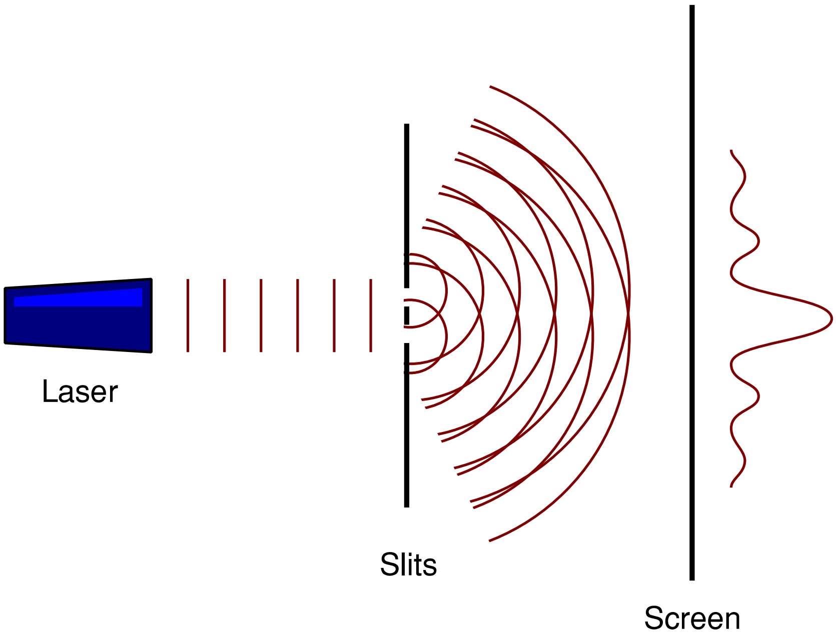
If you lift the empty shell, then the pebble must be under the other shell, so half the time, you win.

But if you uncover the pebble, it ***explodes***, and so half the time, you lose.

Is it possible to do better than just breaking even?

The Young's Slits Experiment

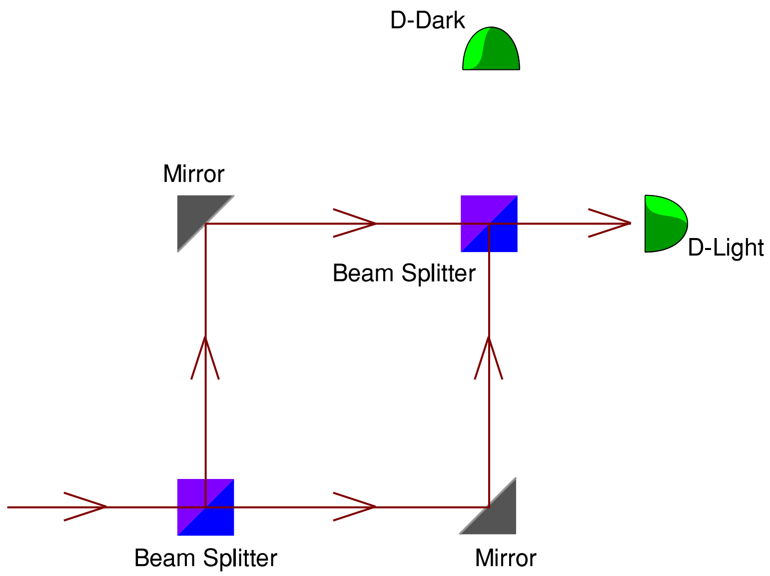
Cast your mind back...



We observe the interference fringes, even if photons are sent through the slits one by one.

If we try to measure which slit the photons pass through, or if one of the slits is blocked, the fringes disappear.

Single Photon Two Path Interference



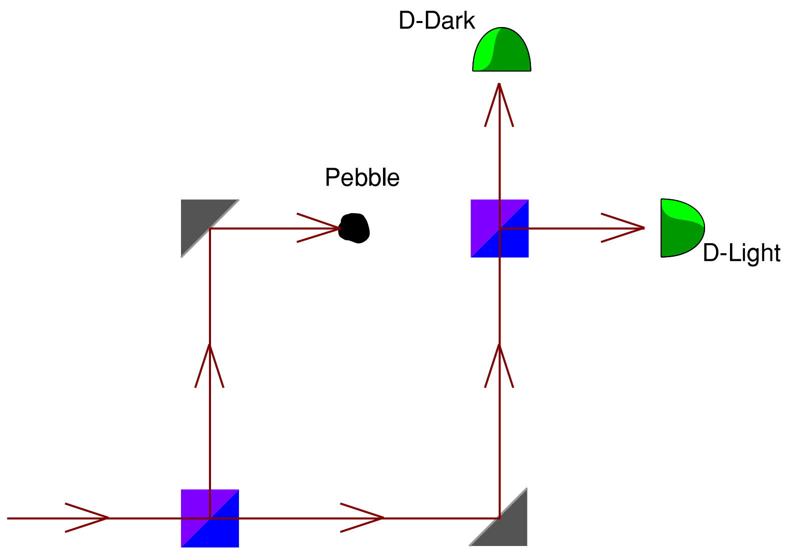
The interference between the two paths means that:

D-Dark never detects a photon.
D-Light detects every photon.

But what if we block one of the paths?

25% Interaction Free Measurement

We place the pebble in the upper path:



The interference is destroyed by the pebble blocking the path.

There is now a 25% chance of a photon arriving at D-Dark .

When this happens, we will have detected the presence of the pebble without interacting with it.

This has been experimentally verified.

Back To The Game

If we use this experiment on one of the shells in the game...

25% of the time, we will destroy
the pebble, and lose.

12.5% of the time, D-Dark will fire.
We will have detected the pebble without
it exploding, and so win.

The rest (62.5%) of the time, D-Light will fire.
The shell is more likely to be empty, and we will
win 50% of the (total) time.

Overall, we will win 62.5% of the time.

We have beaten the odds

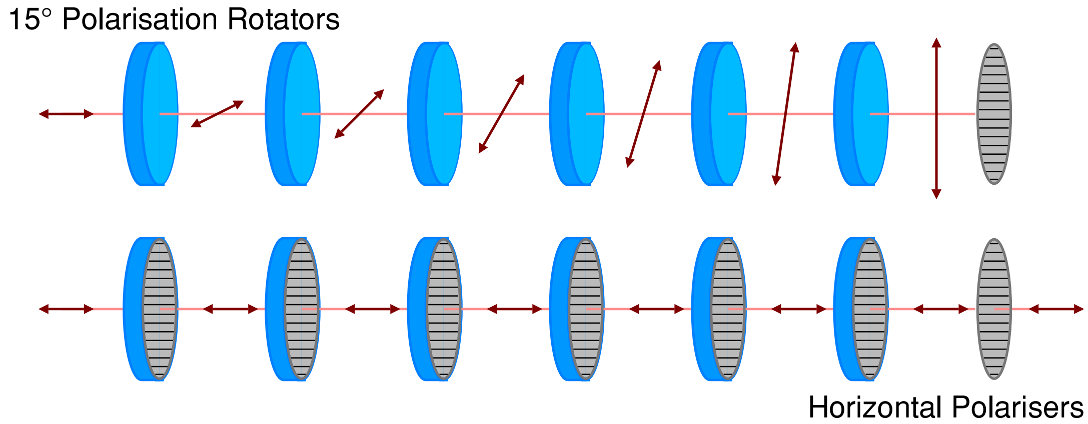
Not only have we shown that interaction-free
measurements are possible...

We can do better.

The Quantum Zeno Effect

We pass horizontally polarised photons through an array of six 15° polarisation rotators.

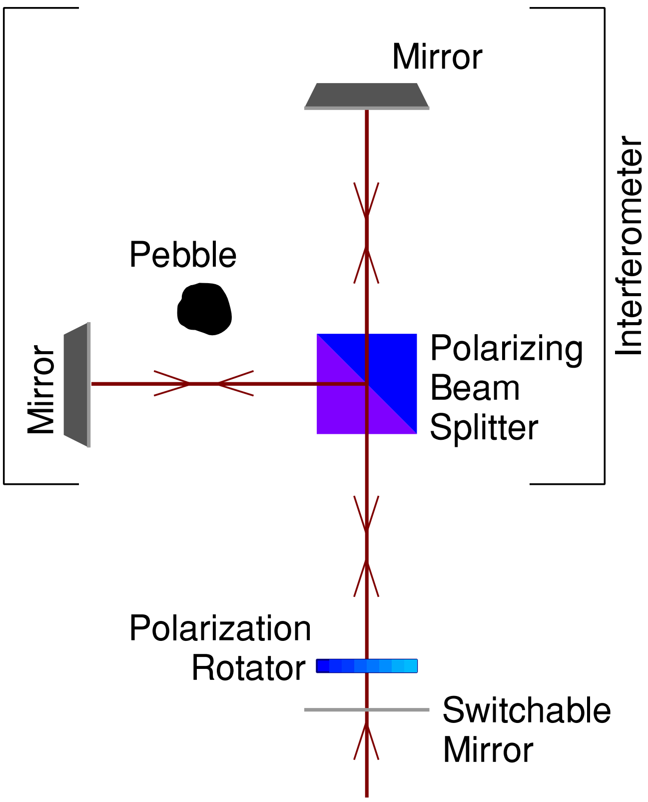
The photon ends up vertically polarised, and is absorbed by the horizontal polariser.



If we place a horizontal polariser after each rotator, we stop the photon's polarisation from rotating, but the photon may be absorbed along the way.

If we increase the number of stages (N), the probability of losing the photon decreases as $(\cos^2(90°/N))^N$.

Almost 100% Interaction Free Measurement



A horizontally polarised photon is sent into the device via the switchable mirror at the bottom. This mirror is timed to make the photon go through the system N times.

The polarising beam splitter sends horizontally and vertically polarised light in different directions.

If the interferometer is clear, the photon will leave the system vertically polarised.

But, if the vertical-polarisation path is blocked by the pebble, this will inhibit the rotation of the polarisation, and the photon will leave the system horizontally polarised.

The photon may be absorbed, but $P_{abs} = (\cos^2(90°/N))^N$.

Conclusion

Quantum optics allows us to ‘see’ an object when there is only a small chance of directly interacting with it.

Theoretically, the probability of an interaction free measurement can be arbitrarily close to 1.0.

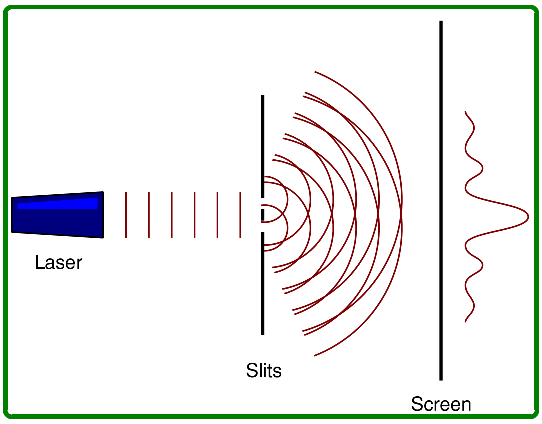
Up to 70% success rate achieved in experiments.

May lead to low/no interaction ‘photography’, e.g.

Low dosage X-ray process.

Imaging of Bose-Einstein condensates.

'The Jackson Proposal'



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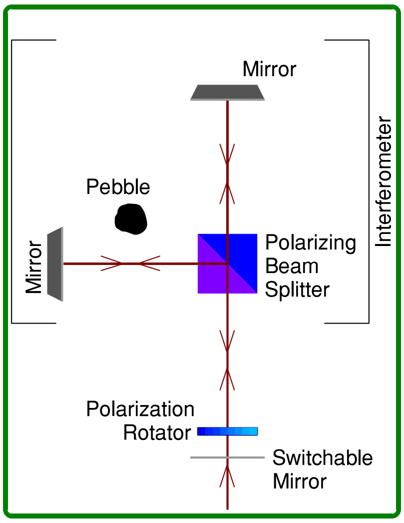

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The behaviour of the Young's Slits (when performed using electrons) is usually rationalized by saying that trying to measure which slit the electron goes through gives it a momentum kick, which destroys the interference pattern (originally suggested by Niels Bohr, I think).

However, if we can measure which slit the electron passes through without interaction with it, this explanation fails.

So what would happen?