

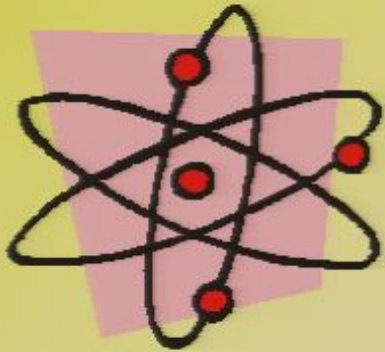
Title: The Weird World of Quantum Physics - Part 1

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URL: <http://pirsa.org/06070069>

Abstract:

The Weird World of Quantum Physics



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Summary

- What is quantum physics?
- Where does it fit into the big picture of physics?
- What is light made of?
- Experiments with light (photons) and mirrors.
- Core concepts of quantum physics
 - superposition
 - genuine randomness
 - wave-particle duality
 - discreteness
 - Heisenberg's uncertainty principle

What is quantum physics?

- **Quantum physics (a.k.a. quantum mechanics)** is a scientific theory primarily about how the 'tiny' objects --- such atoms, electrons and photons --- that make up all physical objects move around and interact or collide with each other. In other words, it is about their motion and what they do when they come near each other.
- eg. how electrons jump from one energy level to another within atoms, giving off or absorbing photons as they do so.
- How the Americium atoms in your smoke detector and other radioactive atoms decay into other elements.

How small is 'tiny'?

- When we said that quantum physics was primarily about 'tiny' objects, what size did we mean by this?

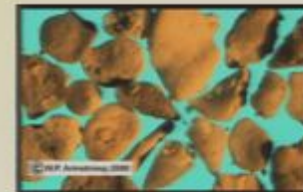
A Human Being (1 metre)



An Ant (0.01 metres)



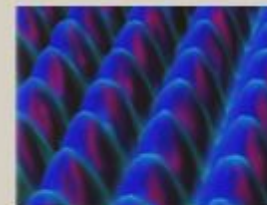
A Grain of Sand (0.0001 metres or 10^{-4} metres)



The flu virus (0.0000001 metres or 10^{-7} metres)



An atom (0.0000000001 metres or 10^{-10} metres)



Student activity.

- Assuming that all atoms are spherical and all have radii of 10^{-10} metres, how many atoms are there in a Mars bar chocolate?

Assume that the Mars bar is rectangular with the following dimensions:
1 cm x 1cm x 5 cm.

Neglect the effect of gaps between adjacent atoms in your calculations.

Formula for the volume V of a sphere is $V = \frac{4}{3} \pi r^3$.

Columns
5ft
6ft
Columns
X
1-19 x 10²⁴

1cm = 10^{-2m}

Columns

1.19 x 10²⁴

1cm = 10⁻²m

- Quantum physics is currently science's best theory of the subatomic world of electrons, protons and neutrons



- *It is phenomenally accurate.* Correctly predicts certain properties of subatomic particles to within one part in 10 billion. If we could predict the distance from Toronto to Waterloo with the same accuracy, then our prediction would be correct to within a 1/100 of a millimeter!



- *It is counter-intuitive.* An atom is a million times smaller than a grain of sand. At the level of individual atoms, quantum mechanics say that many strange phenomena occur all of the time.



Where does quantum physics fit into the grand scheme of physics?

- Twin pillars of 20th century physics.
- Quantum physics: physics of the small.
Electromagnetism, weak and strong nuclear forces.
- General relativity: Physics of the large.
Stars, galaxies, black holes
Gravity.

In the 17th century, Isaac Newton discovered that the same force that caused Earth to revolve around the sun was also responsible for apples falling from trees

Universal theory of gravity.

Is there a 'universal' theory that combines gravity and quantum physics?

Einstein spent the last 30 years of his life looking for something similar but failed.

Holy grail of theoretical physics today.

Superstring theory.

24

$$1 \text{ cm} = 10^{-2} \text{ m}$$

$$10^{-35} \text{ m}$$

Planck length

→ 25 orders



Is a theory of everything possible?

- *People say to me, "Are you looking for the ultimate laws of physics?" No, I'm not... If it turns out there is a simple ultimate law which explains everything, so be it — that would be very nice to discover. If it turns out it's like an onion with millions of layers... then that's the way it is.*
— Richard Feynman, Nobel prize winner in physics.



physicists believe that they have finally found a framework for stitching these insights [about the universe together] into a seamless whole --- a single theory that, in principle, is capable of describing all physical phenomena.”

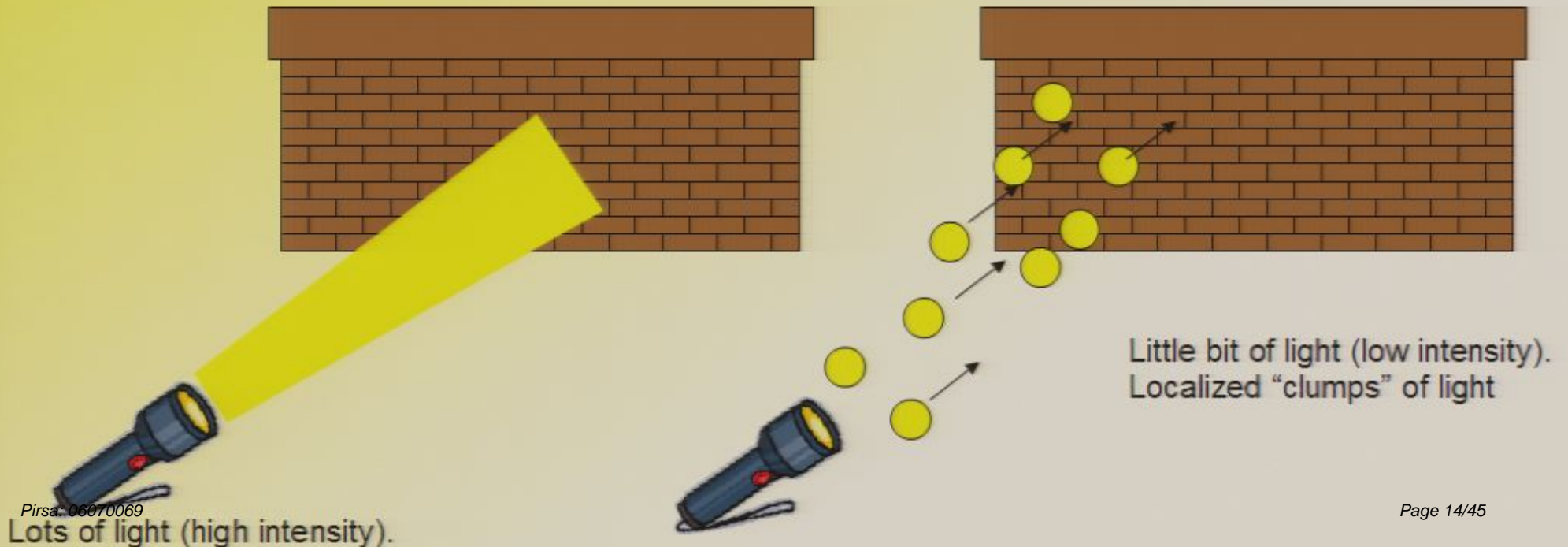
— Brian Greene, string theorist

Thought experiments

- Galileo
- Gravity accelerating all objects at the same rate.
- Einstein.
- What if we ride alongside a beam of light.

What is light made of?

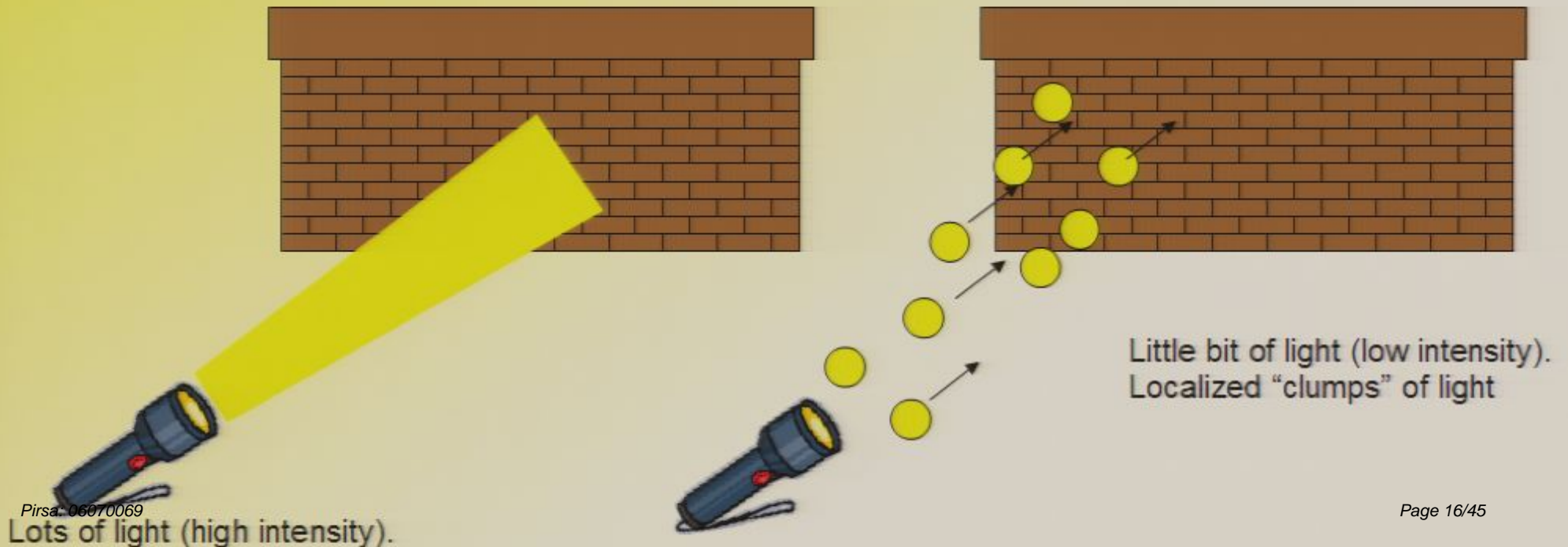
- Imagine shining a flashlight at a wall.
- What happens if we make the flashlight dimmer and dimmer so that only a tiny amount of light hits the wall.
- What do we see? What is light ultimately made of?



- If we placed a series of ultra-sensitive light detectors in the wall, we would eventually see light coming in definite, localized clumps.
(Kind of light particles of light.)
- i.e. light seems to be made up of tiny particles which we call photons
- But, as we shall see, things are much, much more complicated than this.

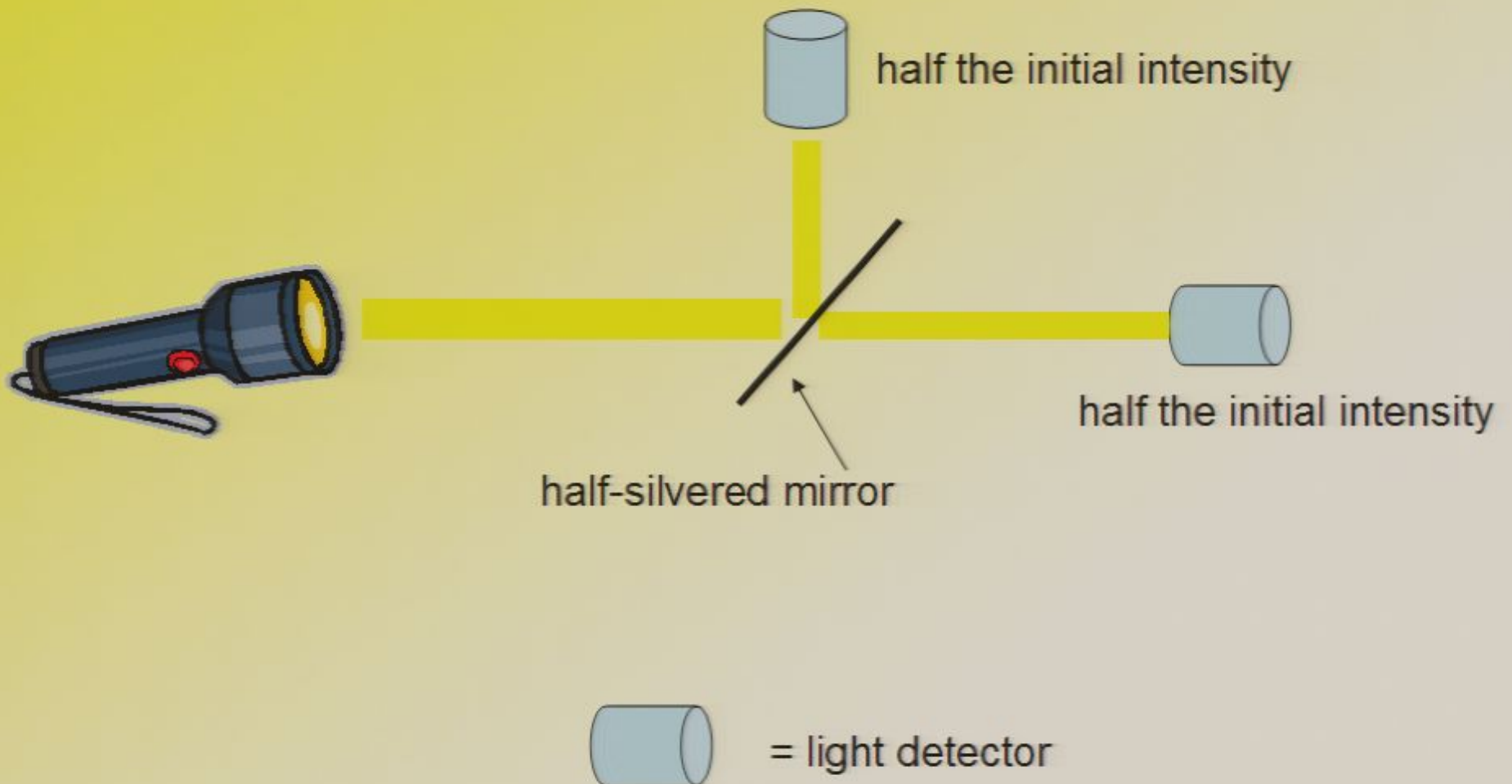
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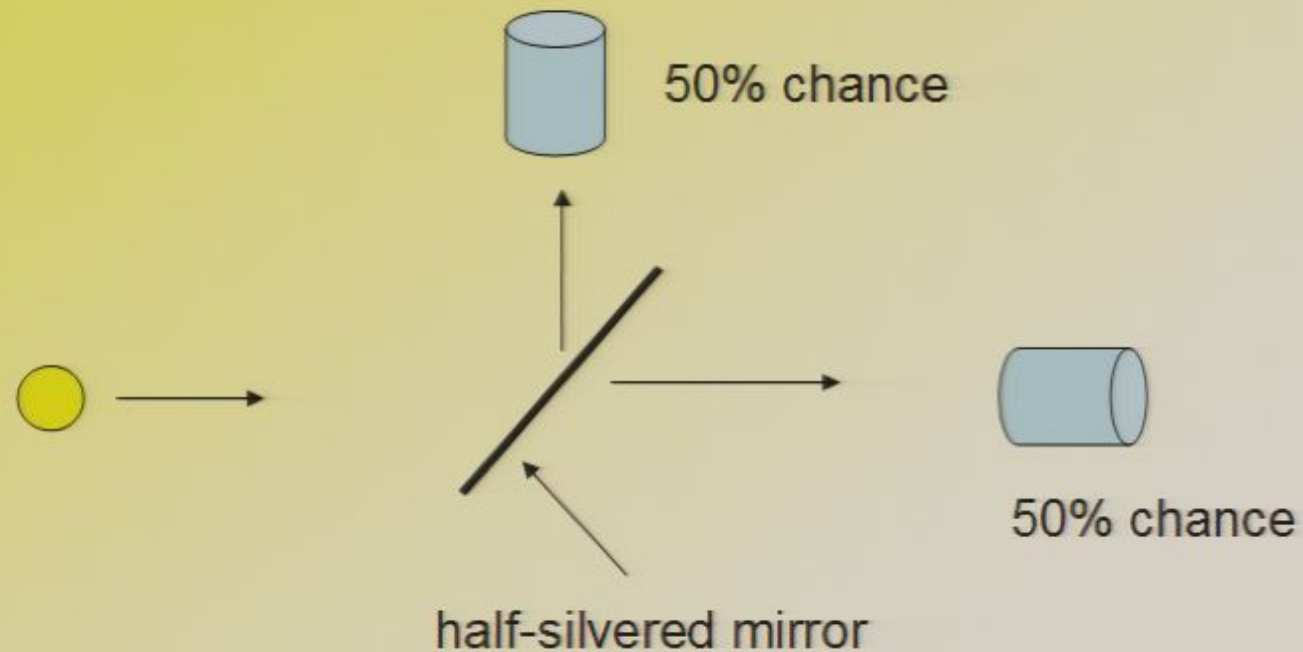


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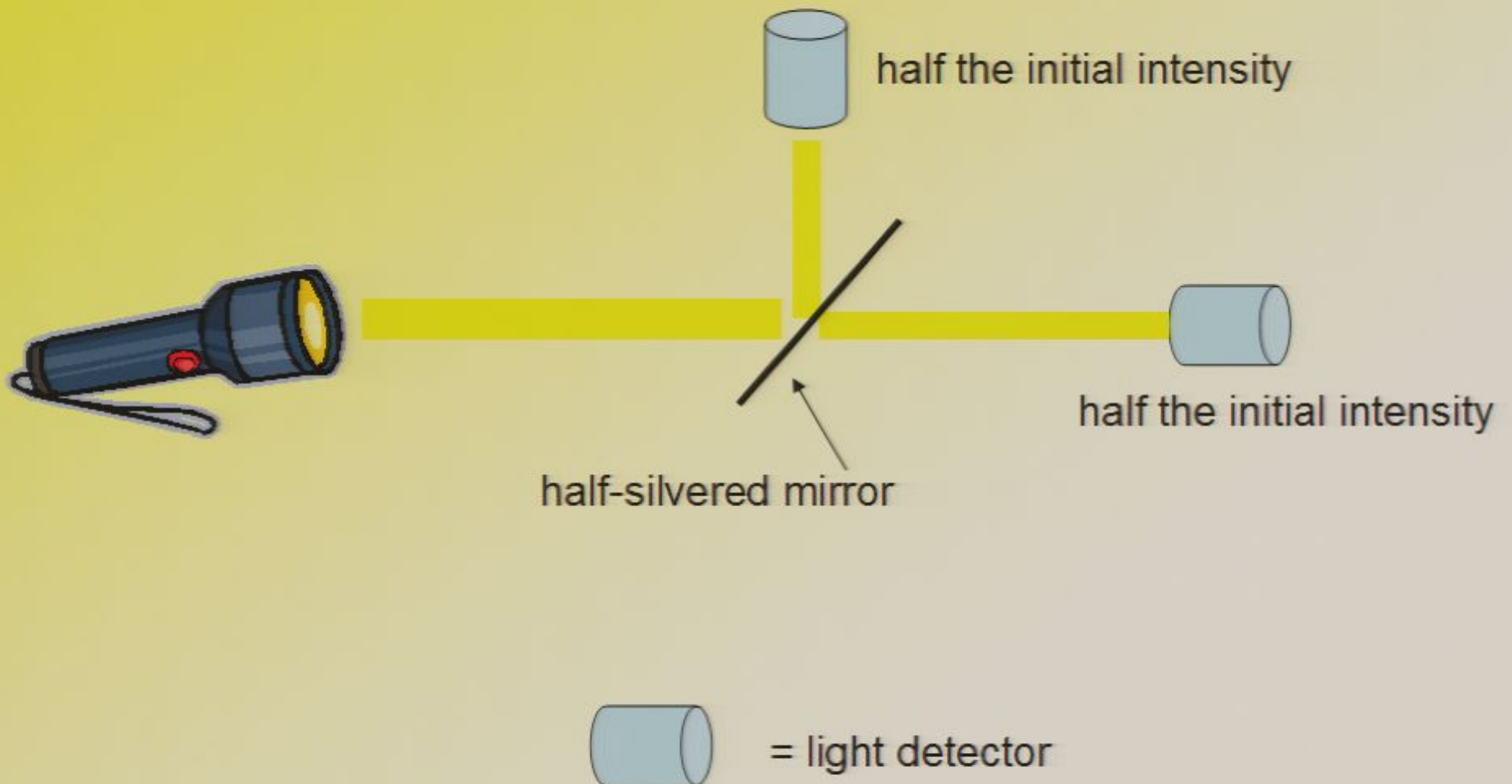
Light shining on a half-silvered mirror



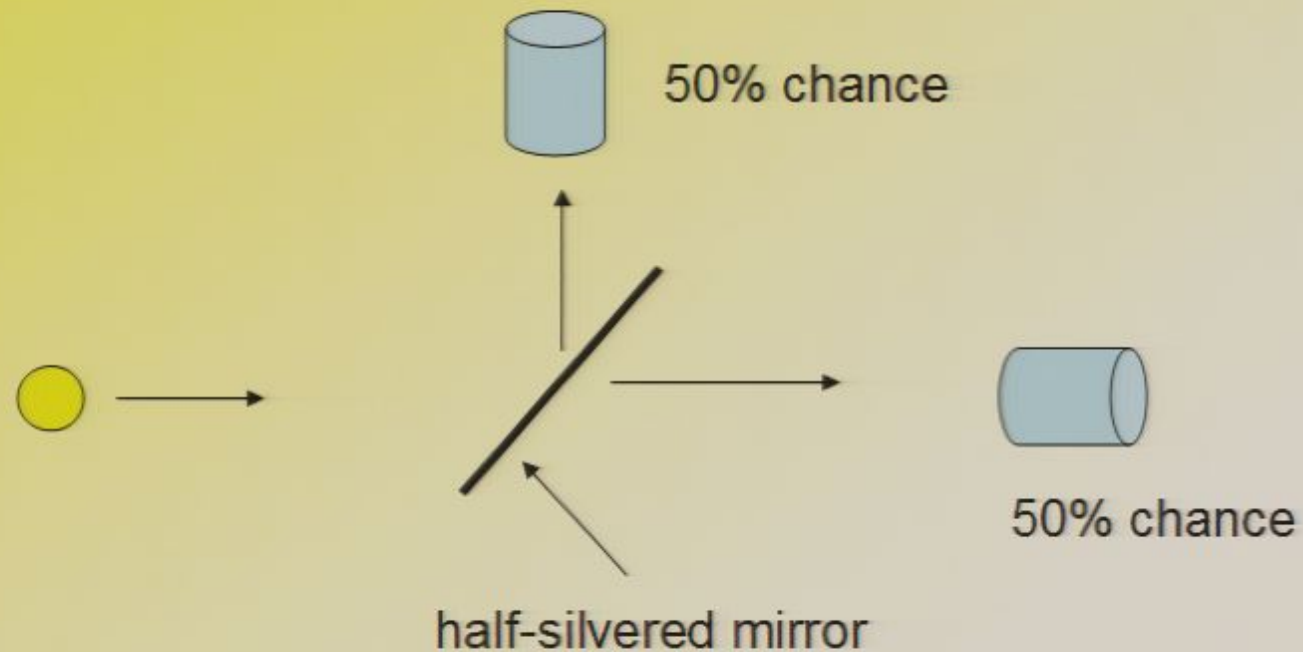
A single photon incident on a half-silvered mirror.



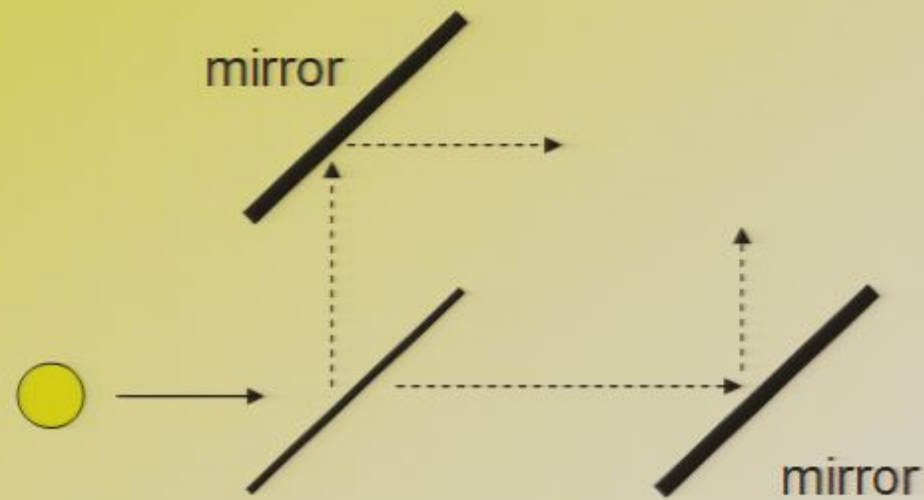
Light shining on a half-silvered mirror



A single photon incident on a half-silvered mirror.



Add some mirrors

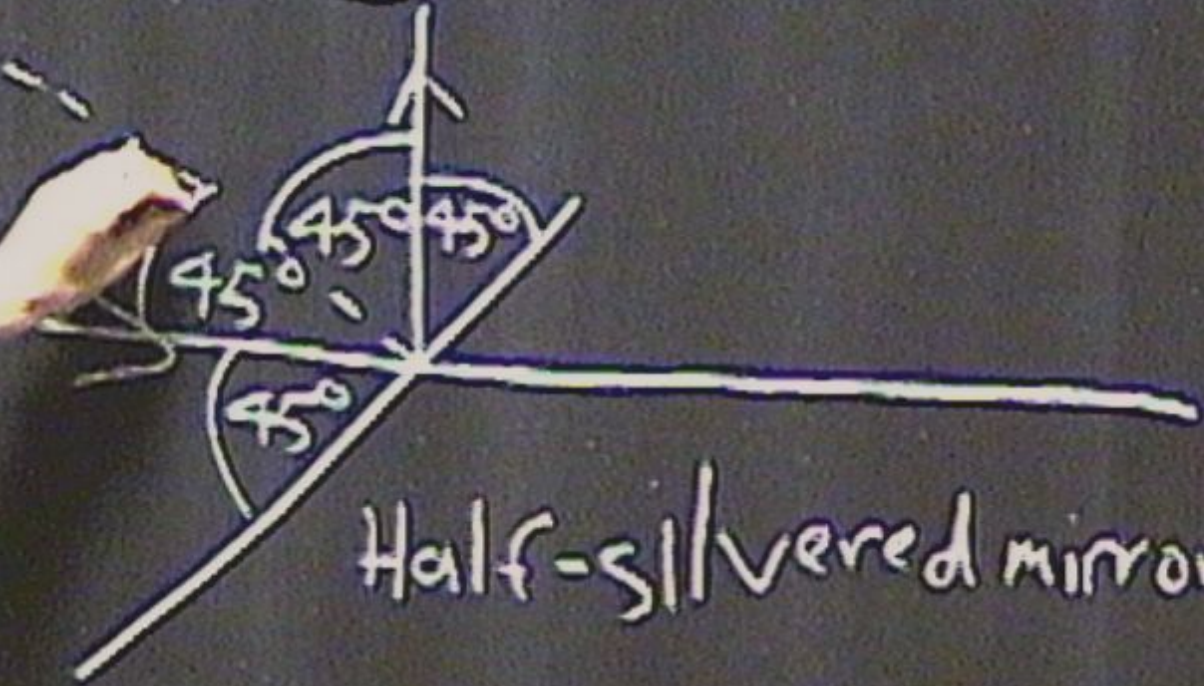


indicates a possible photon path

WERE

NOT

REALLY

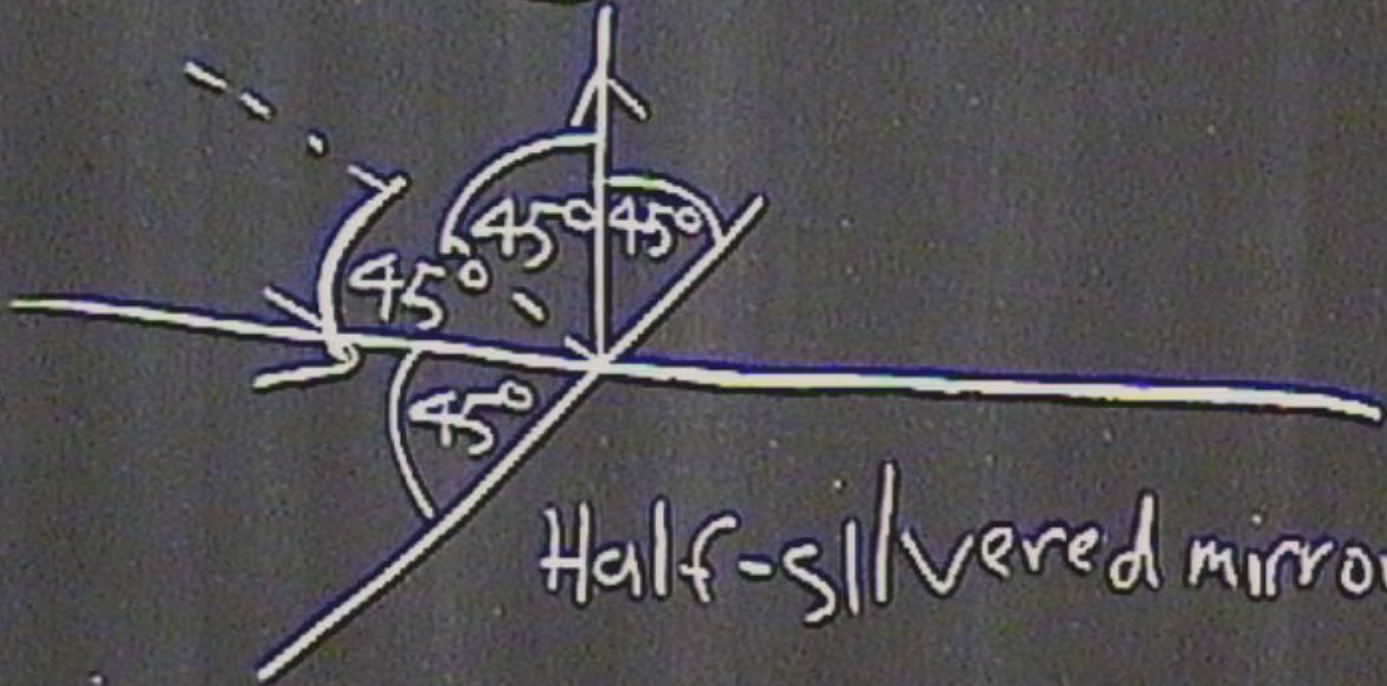


Half-silvered mirror

WERE

NOT

REALLY

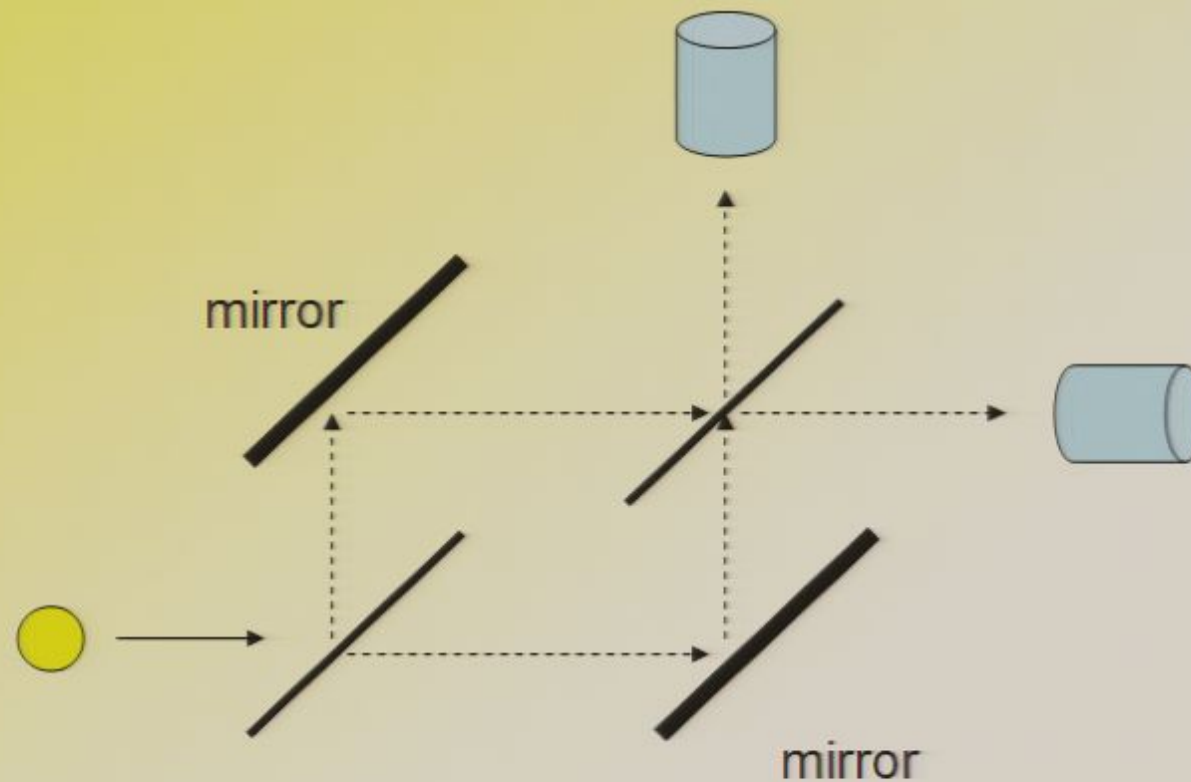


Half-silvered mirror

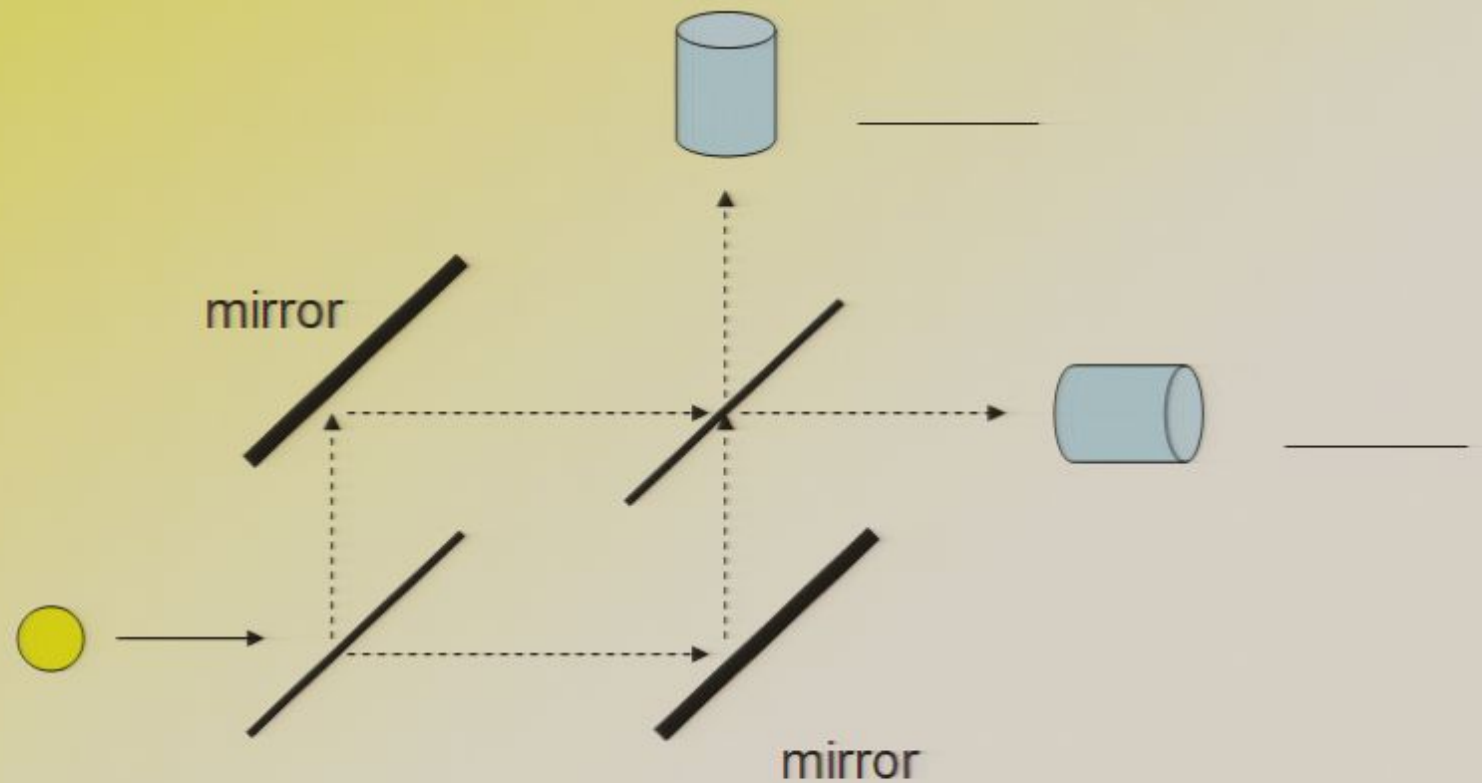
Two half-silvered mirrors

- STUDENT ACTIVITY:

Determine the probabilities of finding a photon at each of the two detectors.

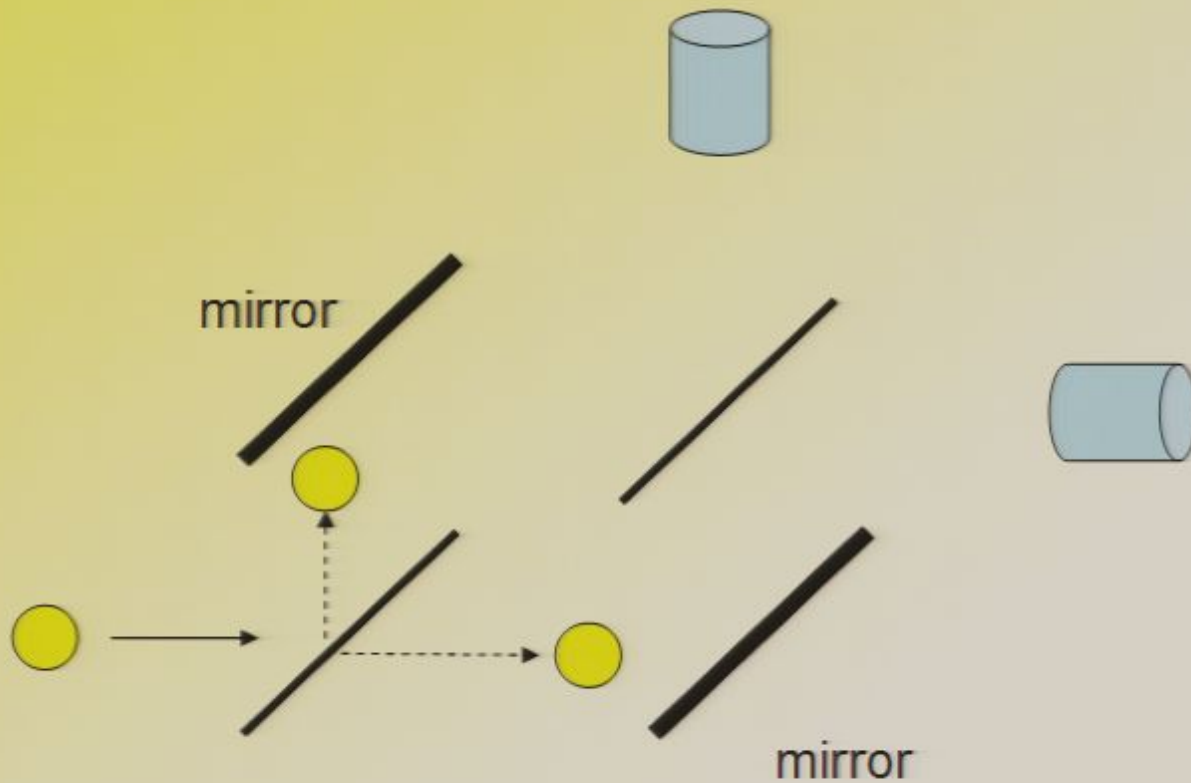


What does quantum theory give?

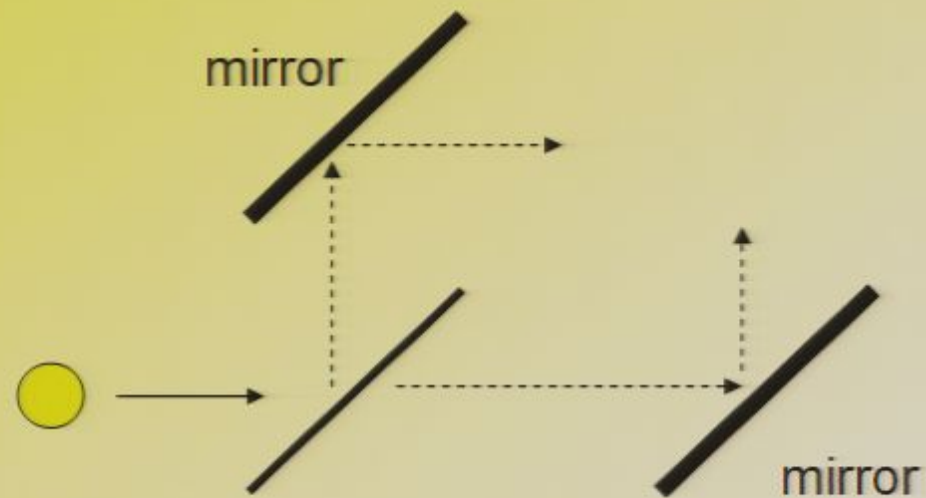


Why?

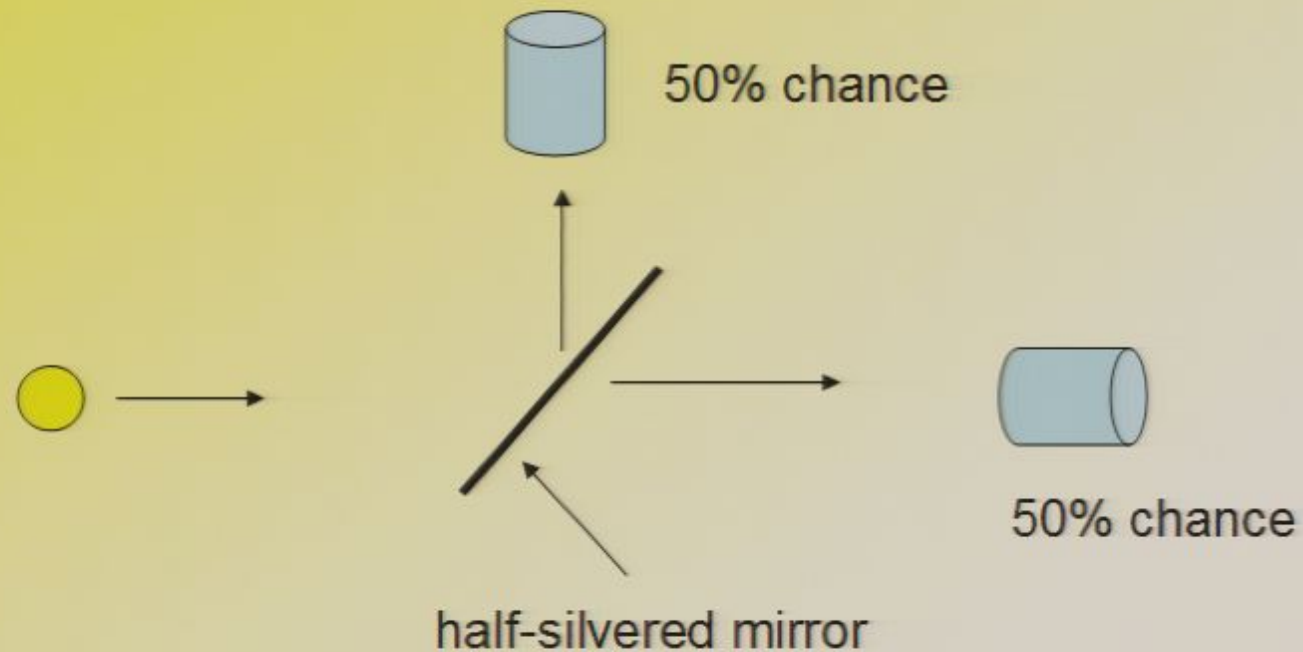
- Each individual photon takes *both* paths.
- Two possible paths to reach each detector
- Overlap between the two leads to constructive or destructive interference (helps to think of wave interference)



Add some mirrors

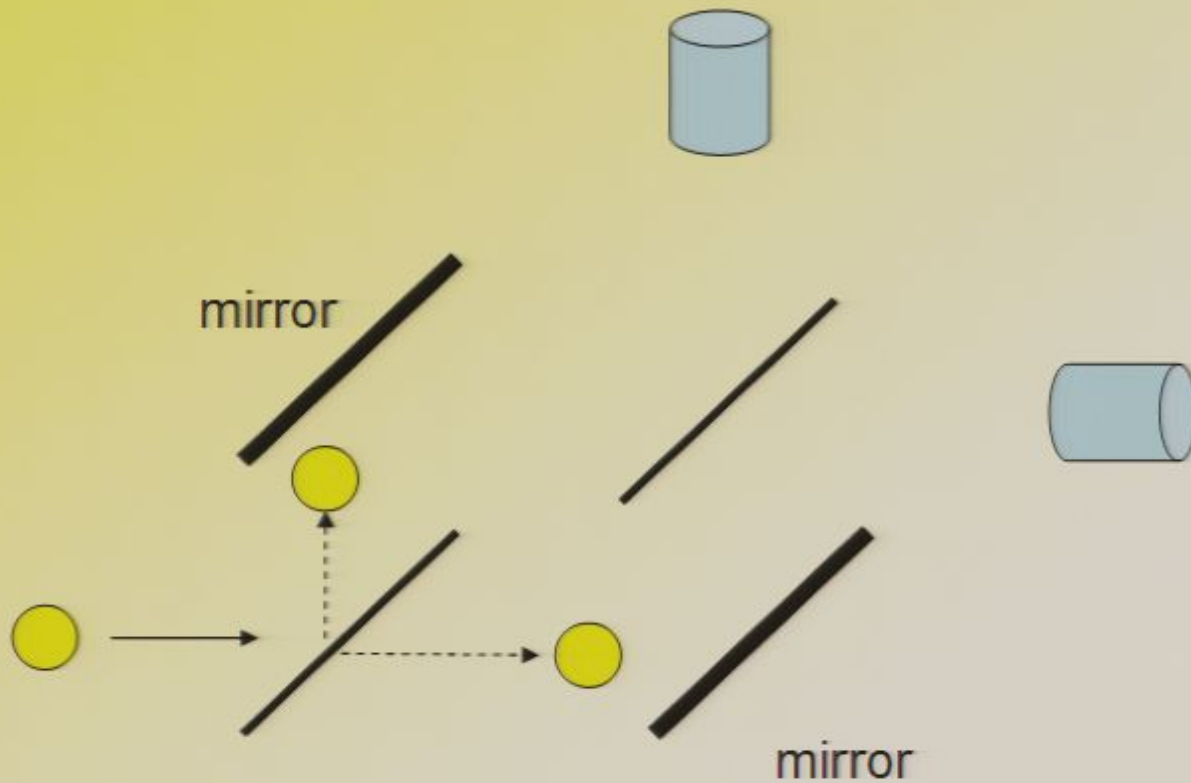


A single photon incident on a half-silvered mirror.

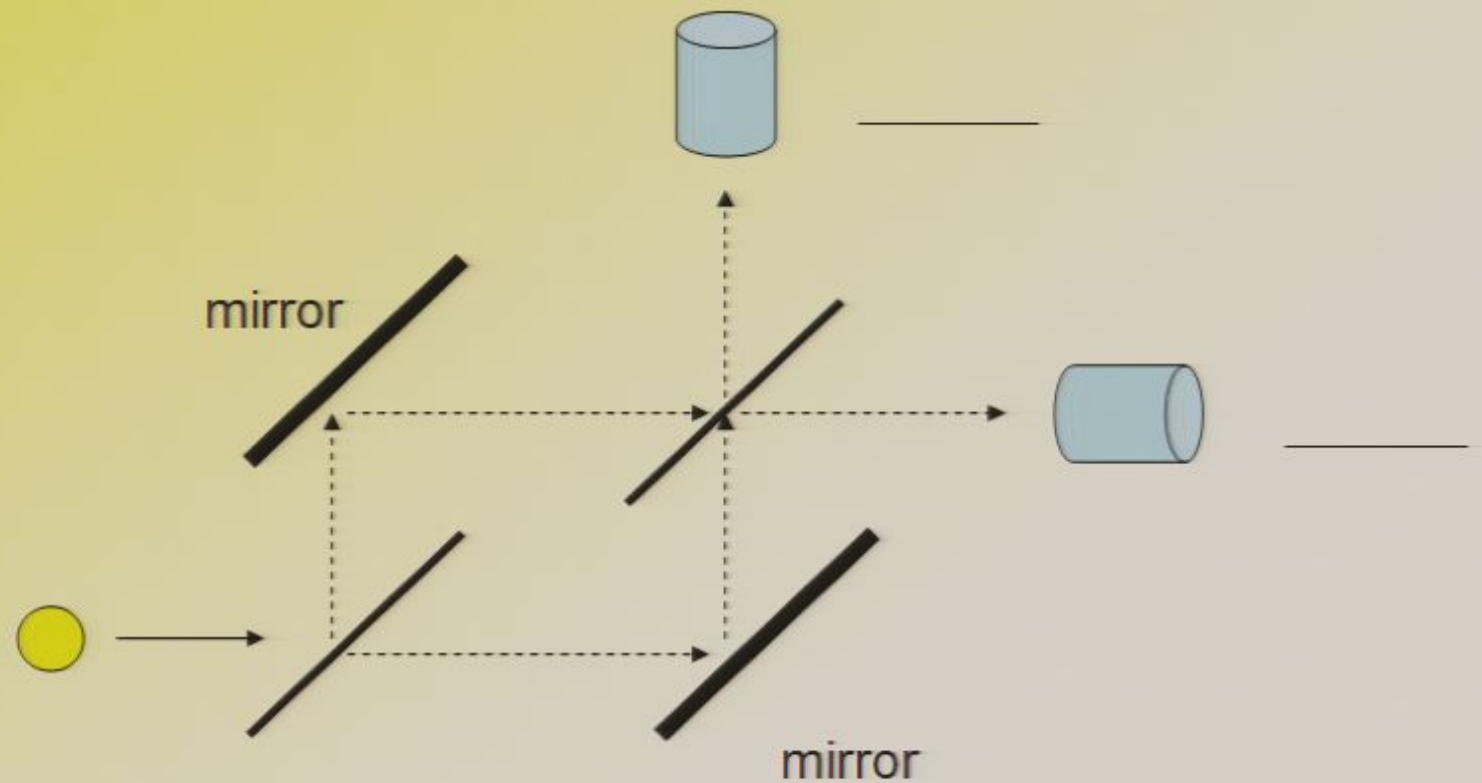


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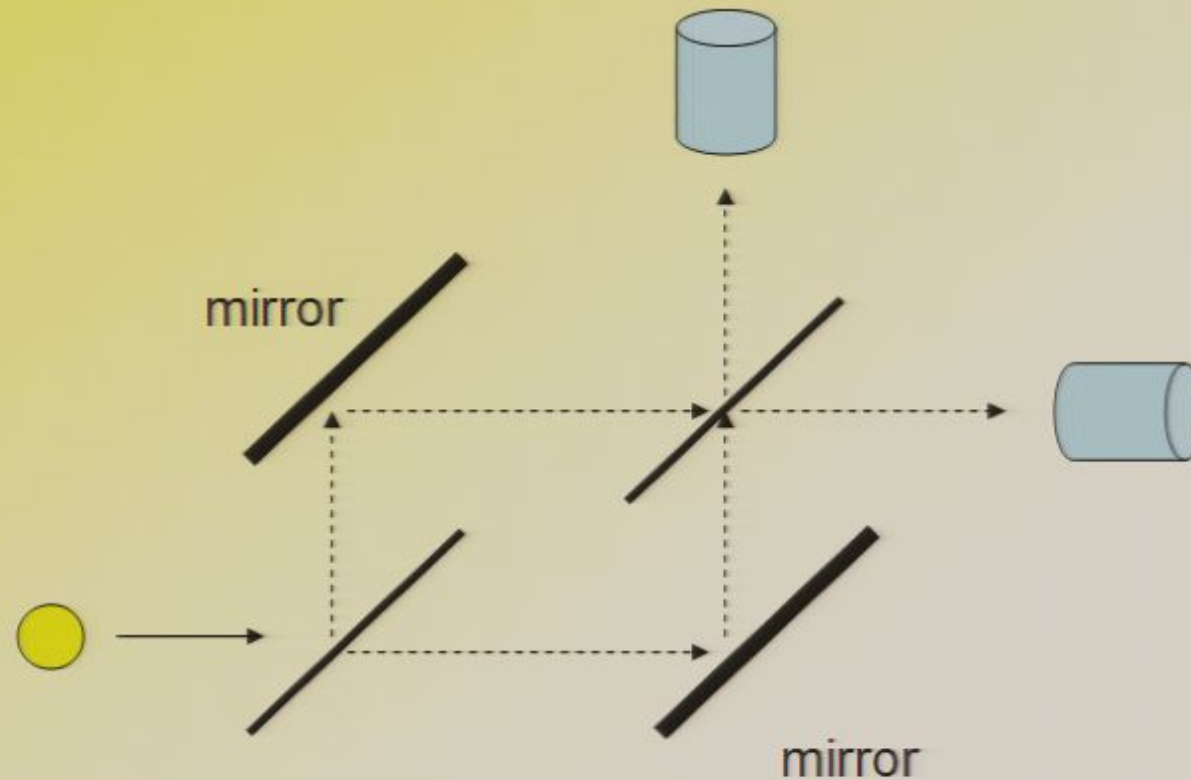
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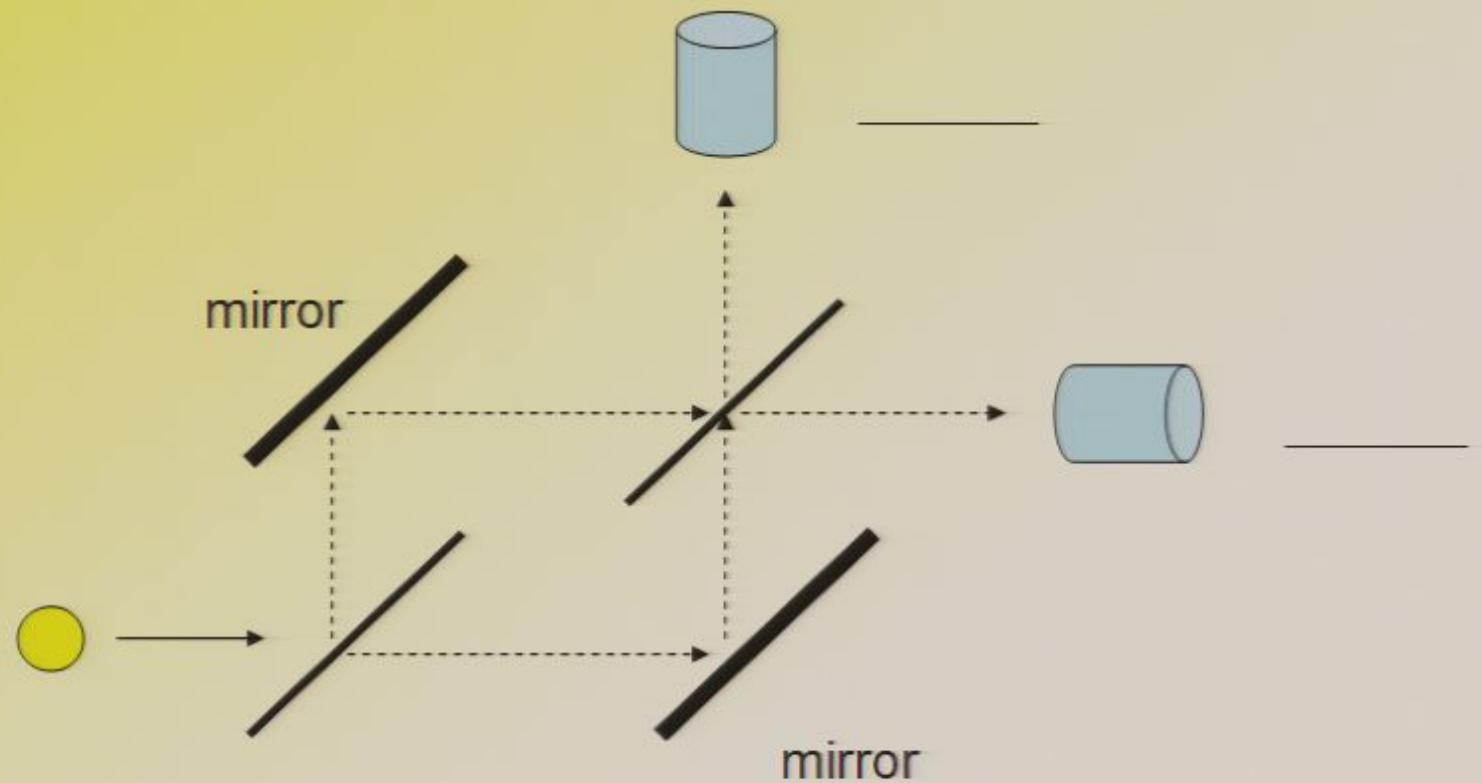
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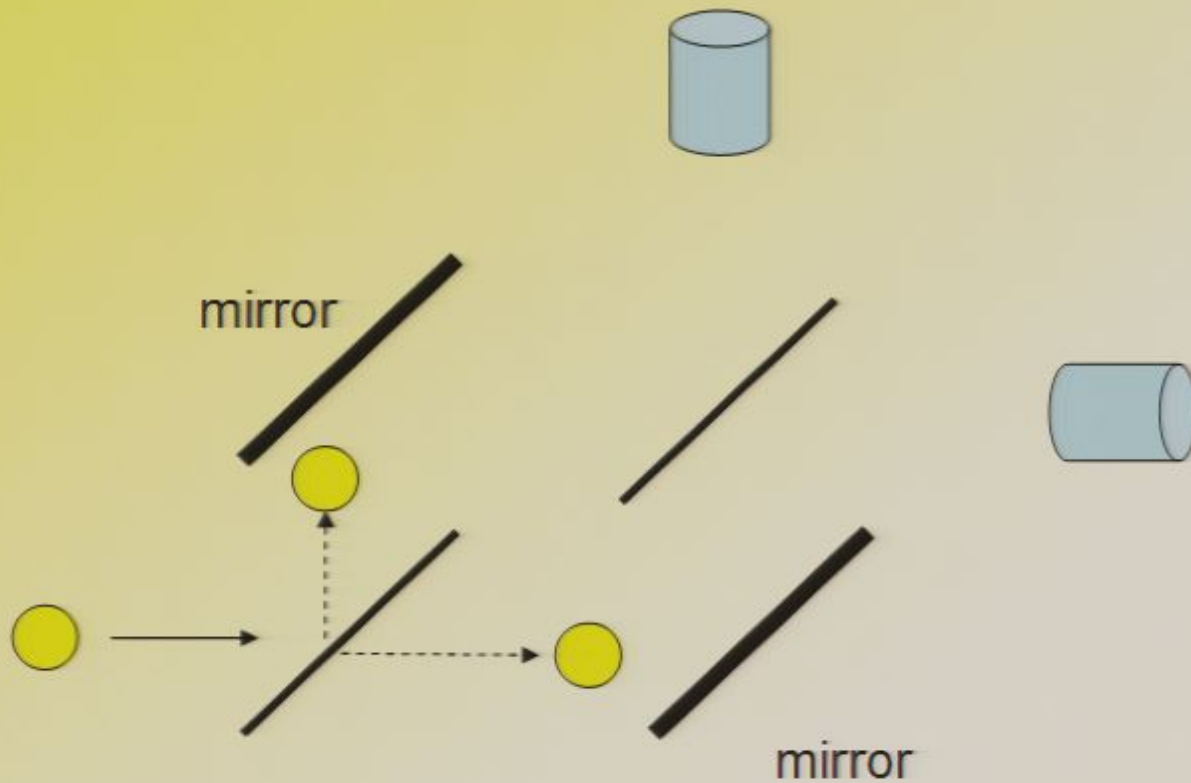


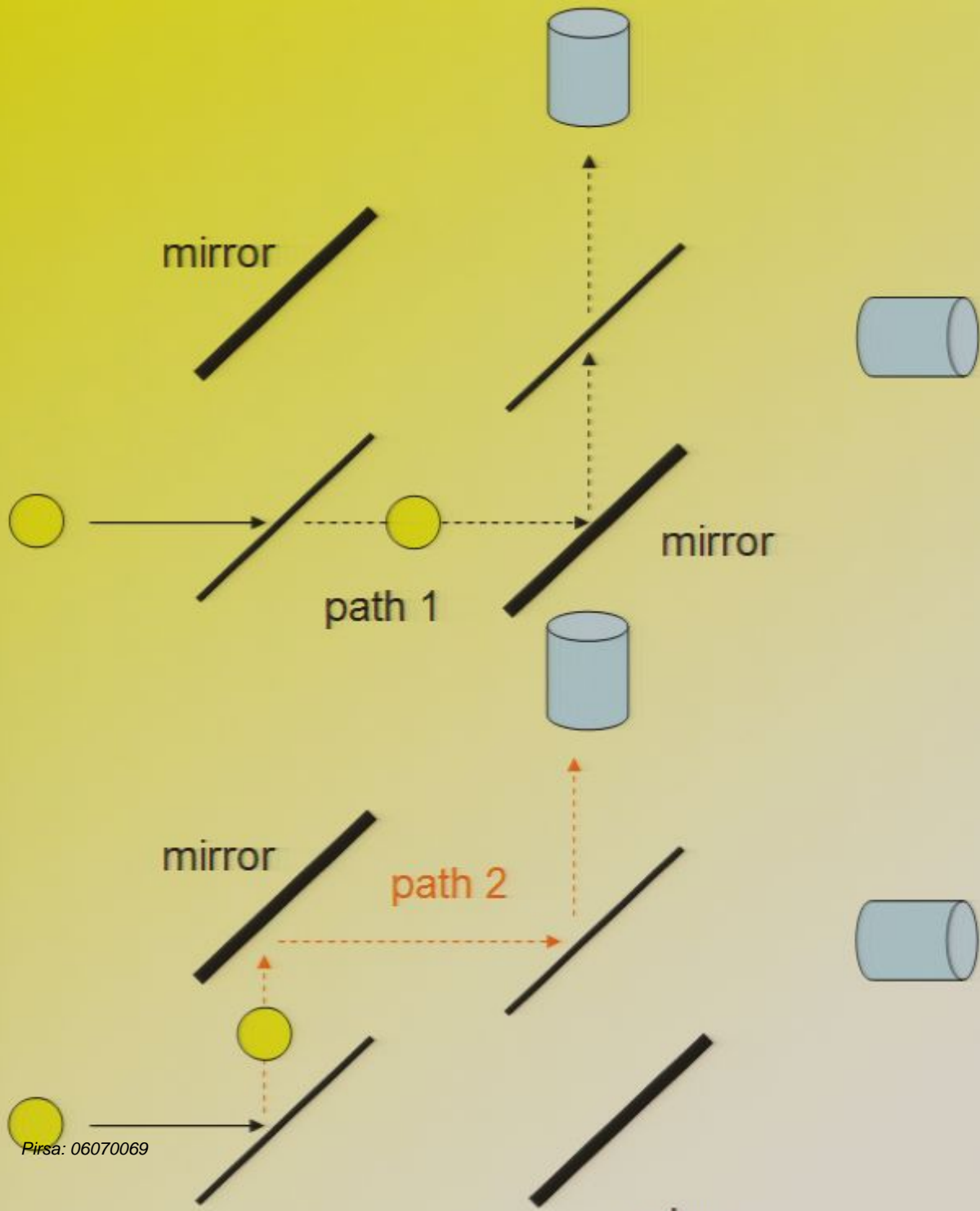
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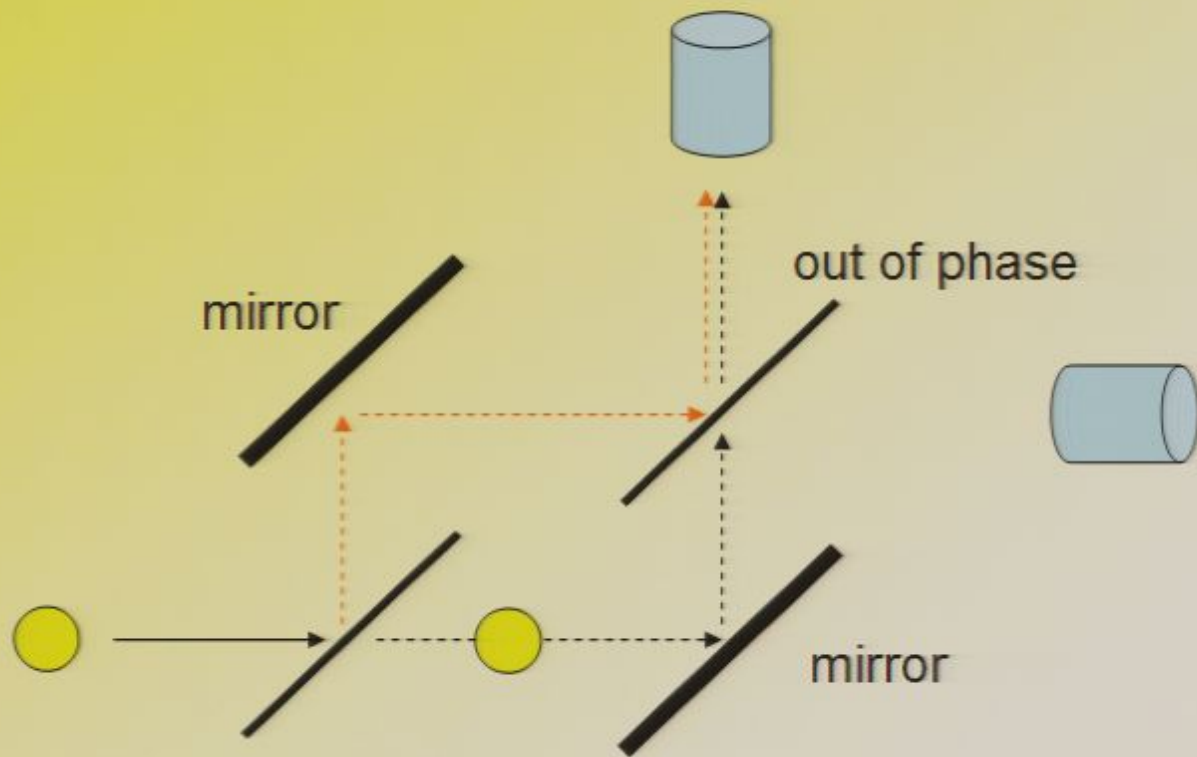


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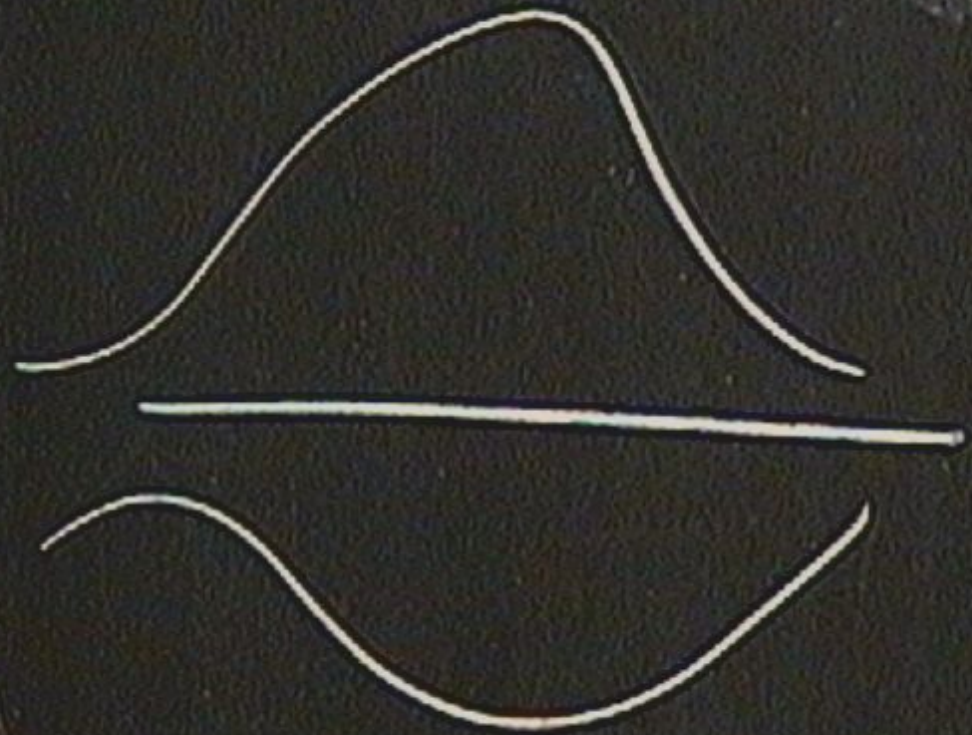






$e^{1/3}$ $\log_2 9$ 9.2

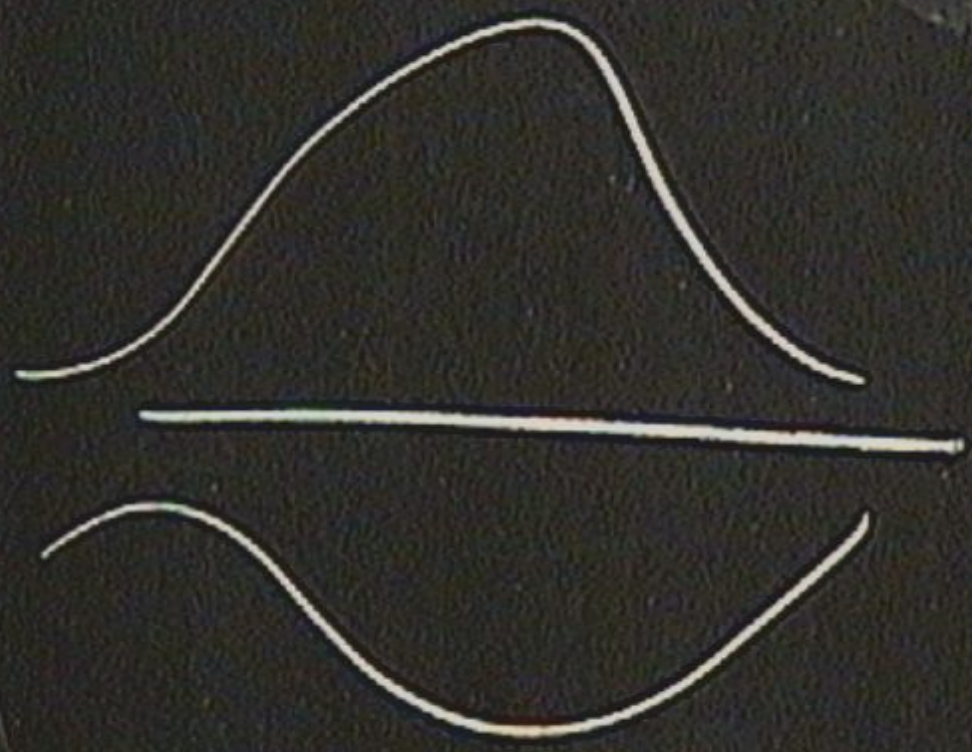
↓
 9.2



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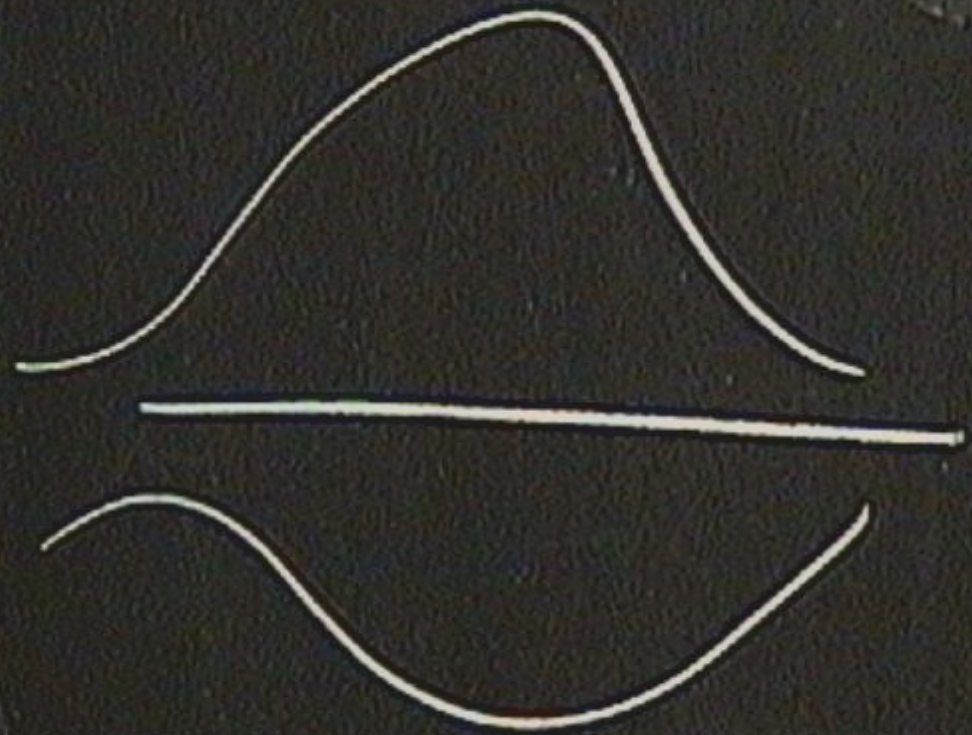


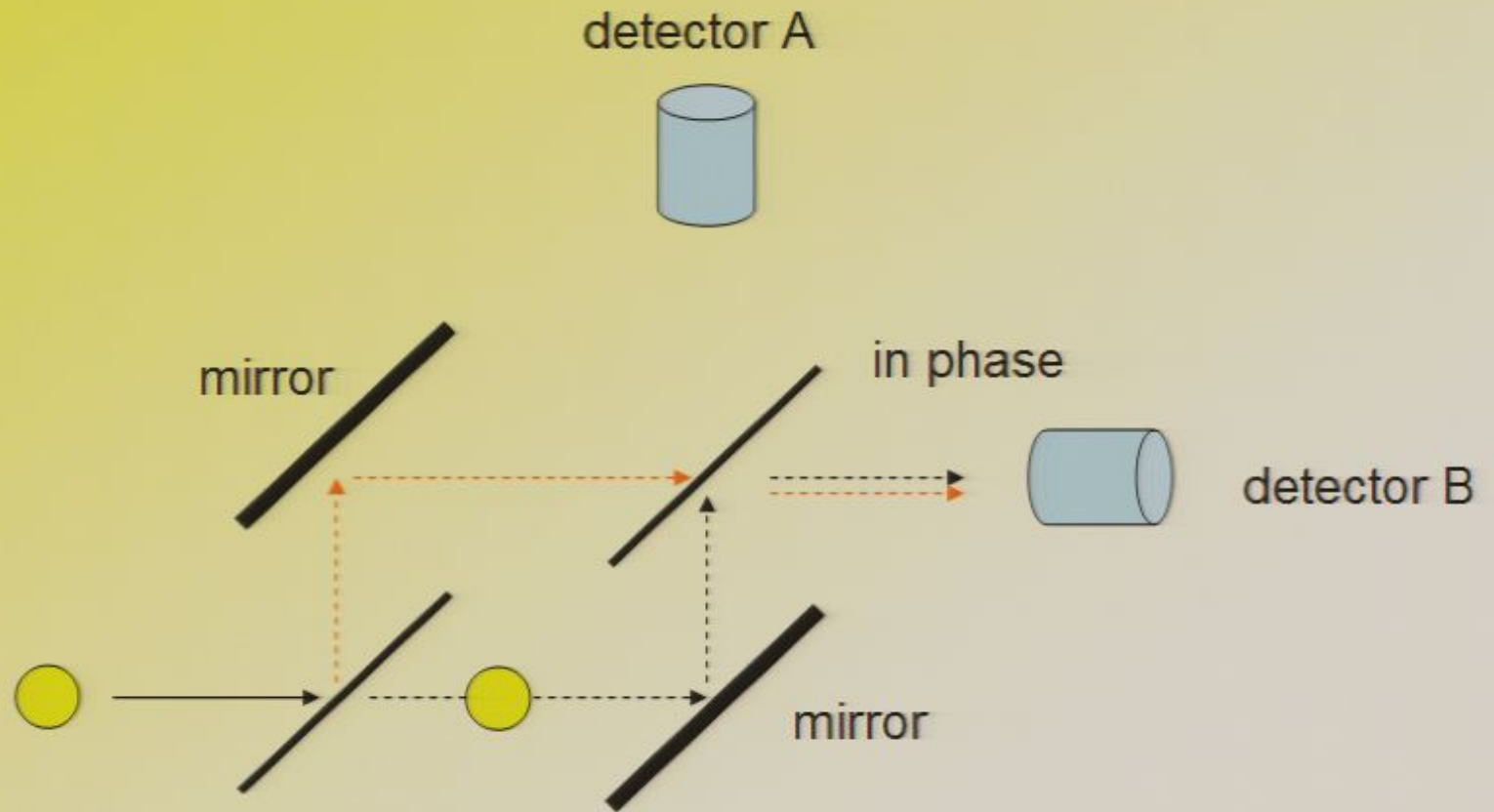
$9,2$



$e^{1/3}$ $\log_2 9$ 9.2

↓
 9.2



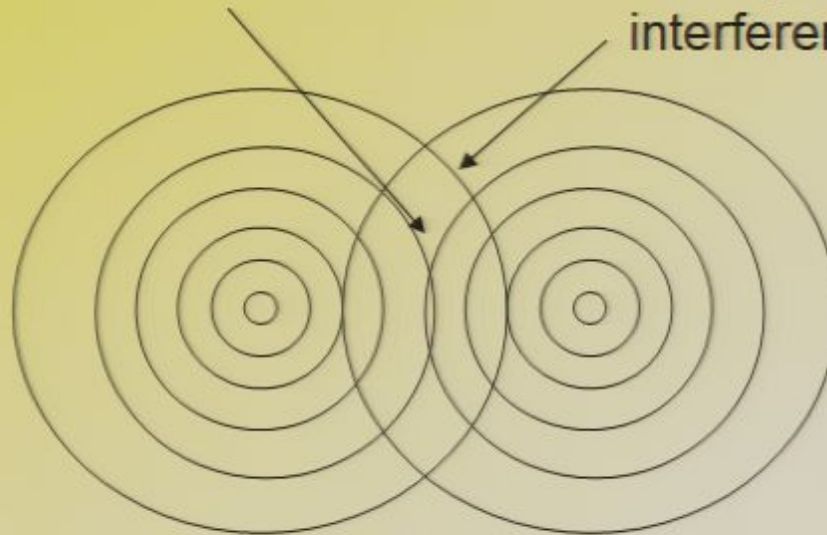


- N.B. We always detect or measure just one photon at detector B, not two as we only ever input one photon into the experiment.

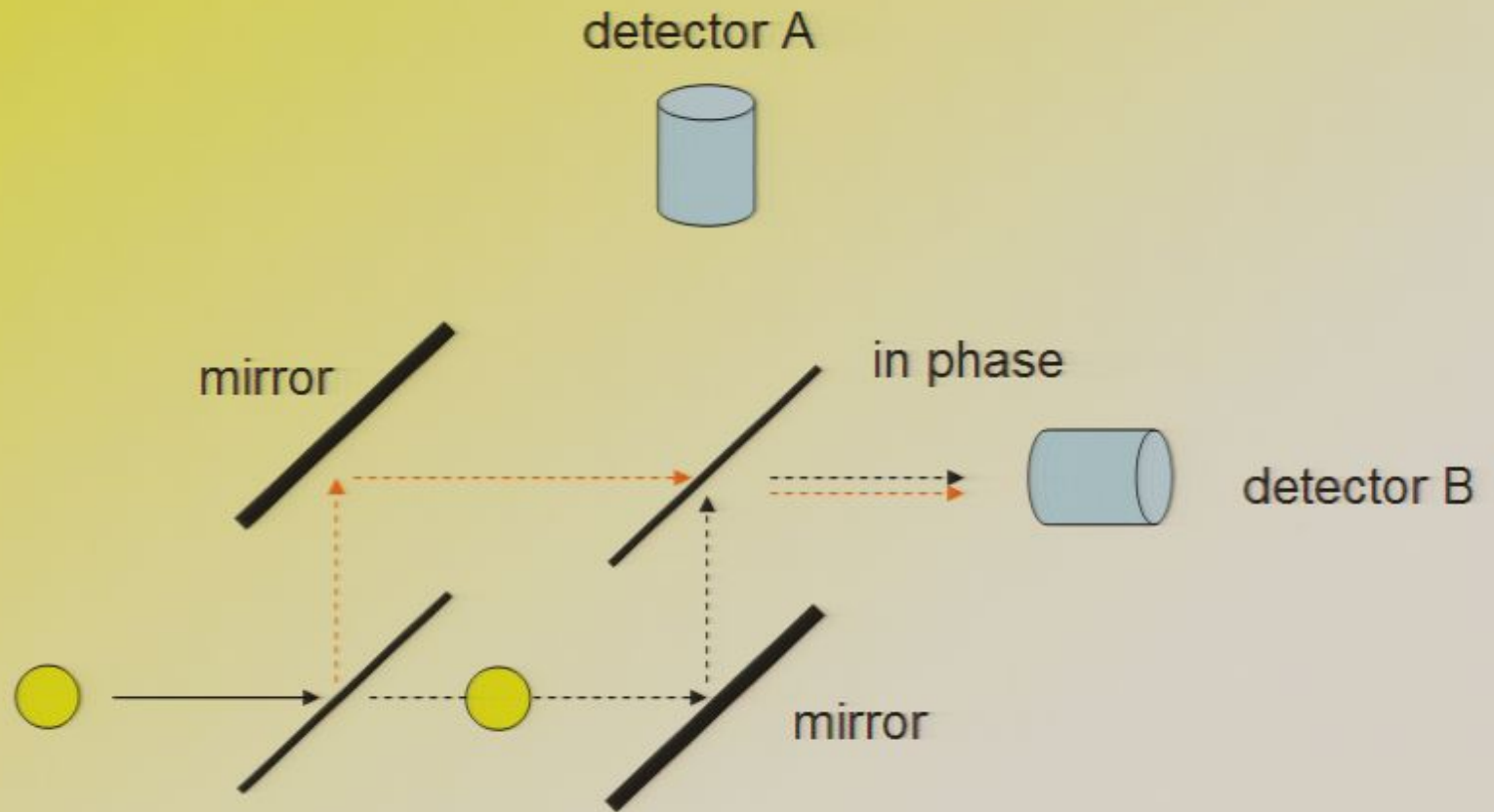
Compare with water waves

in phase: constructive interference

out of phase: destructive interference



Ripples on a pond

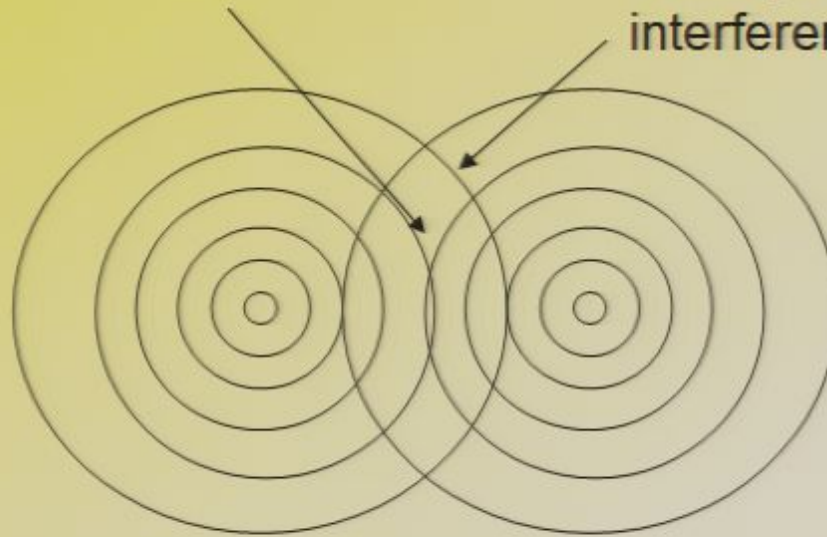


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Ripples on a pond

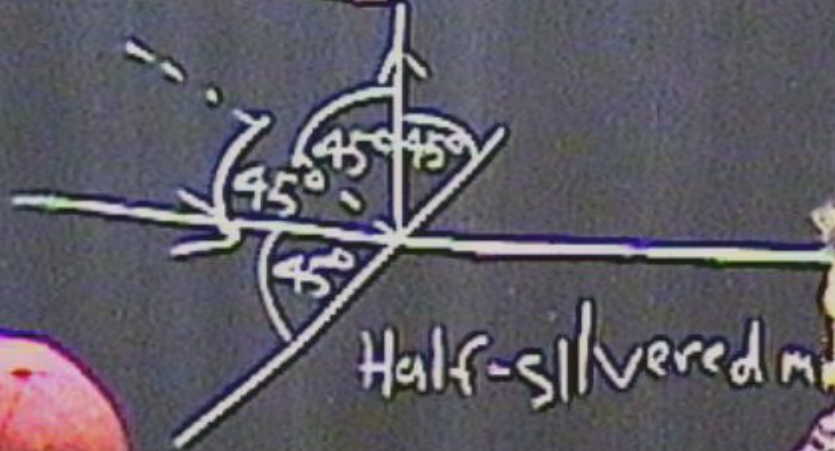
WERE

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$$e^{i\frac{\pi}{2}}$$



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