Particle nature of light / Diffraction + Interference

... But how can light behave like a particle some of the time and like a wave the rest of the time?

Light exhibits what we call wave-particle duality.

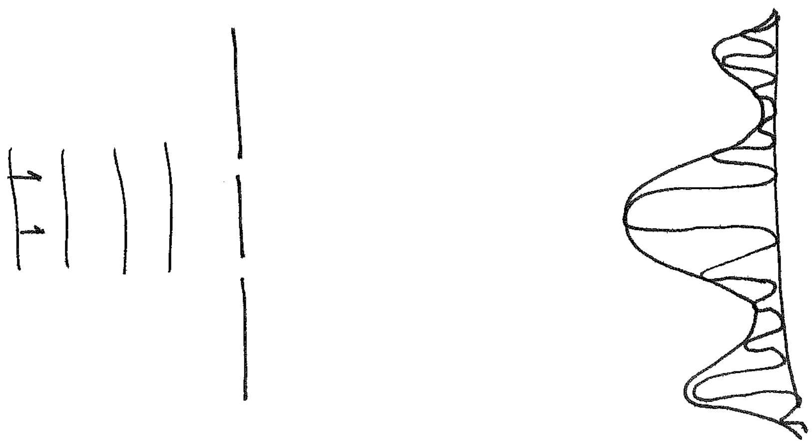
It can behave like a particle, and it can behave like a wave. The behavior that we observe depends on HOW we observe it. That means that if we look for particle-like behavior (design expt to measure particles), then we will find particle-like behavior, and if we look for wave-like behavior, we will find wave-like behavior.

Why does it matter how we observe the light? Shouldn't it always have the same properties, no matter how we measure it?

→ Yes, but our measurements only show us part of the whole behavior...

Let's think back to our double-slit diffraction experiments. If light is really a bunch of particles, and not a wave, shouldn't we be able to tell where each individual photon is going? Shouldn't we be able to tell which slit the photon is going through?

Remember that we said that the light, behaving as a wave, passed through both slits simultaneously, thus creating an interference pattern. We measured this interference pattern by looking at a projection of this behavior on a screen:



this screen is where we took our measurements

But if light is made of particles, then each particle can only pass through one slit or the other - it cannot simultaneously pass through both slits, right?
How do we measure this?

Slow down the laser so that it only emits a single photon at a time. We can put a detector on each one of the slits. When the photon passes through, one detector will blink, and we will know which slit the electron passed through (or maybe both detectors will blink?)

When we do this, we find that sometimes detector 1 blinks, sometimes detector 2 blinks, but the two detectors never blink at the same time.

This means that each photon is only passing through one slit, and the photon never passes through both slits simultaneously

But how does the photon decide which slit to pass through? Are some photons predestined to go through slit 1, and others to go through slit 2?

Let me ask a similar question. If I flip a coin, I can get either heads or tails, but never both. When I flip the coin, how does it decide whether to land on heads or tails?

⟶ The answer is, we can never predict exactly what the coin will do, or what the photon will do.

The very best we can do is to say that if we flip a coin 100 times, ~~50/At~~ we will get tails 50 times. And if we shoot a ~~ph~~ 100 photons at the screen, 50 of them will pass through the right detector.

But we can never say beforehand whether we will get heads or tails, right or left detector.

~~The same is true of the photon~~

So the best we can do is to specify **probabilities**.

$$P_{total} = P_1 + P_2$$

total prob that photon will hit screen

P_1: prob that photon passes through slit 1

P_2: prob that photon passes through slit 2

note on probabilities:

prob A OR B	$P_A + P_B$
prob A AND B	$P_A \cdot P_B$

Because we don't know which slit the photon will pass through, We say that the photon is in a superposition state

$$|\text{photon}\rangle = P_1 |\text{slit } 1\rangle + P_2 |\text{slit } 2\rangle$$

$|\text{photon}\rangle$: state of photon

$|\text{slit } 1\rangle$: photon passes through slit 1

$|\text{slit } 2\rangle$: photon passes through slit 2

The funny brakets $|\rangle$ just denote "state"

This is analogous to saying:

$$|\text{coin}\rangle = \frac{1}{2} |\text{heads}\rangle + \frac{1}{2} |\text{tails}\rangle$$

How does the photon decide where to go? How does the coin decide which side to place up?

~~We will talk more about superposition~~

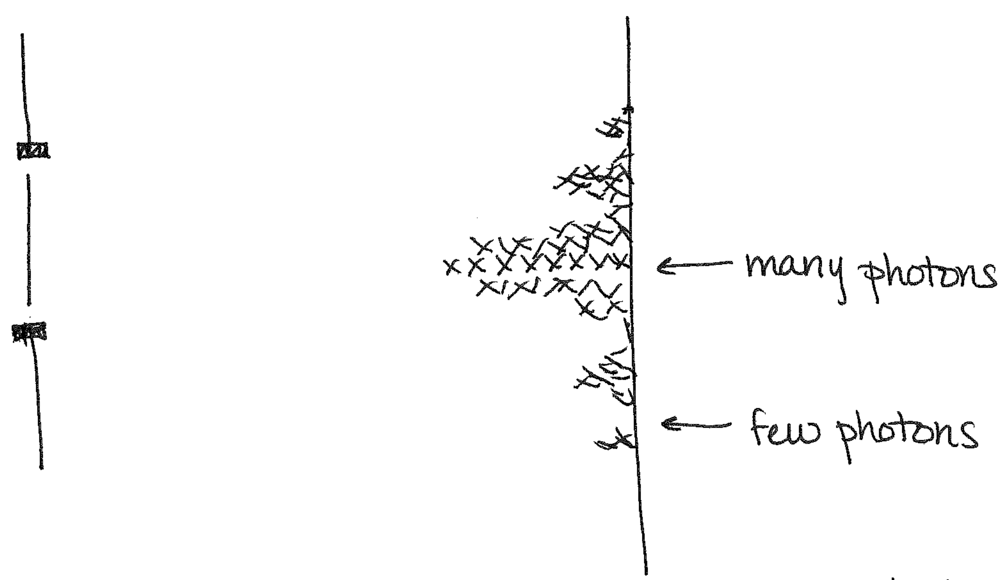
Now here is the wierd ~~[illegible]~~ part:

Until we make a measurement (until we see detector 1 or detector 2 flash), we have to assume that the photon passes through BOTH slits at the same time!

Because in reality, the photon has some probability of passing through each slit, so until we measure it to be sure, we must assume that the photon passes through both.

We will talk about superposition states + measurements later in the course.

Now, back to our double slit. If we keep the detectors on each slit, and we measure each photon as it passes through, can we ever see interference?



as we collect more + more photons on the screen, we build up the interference pattern

OK, but why do some areas on the screen have more photons, and some have less? Are photons repelled from certain parts of screen + attracted to others?

⟶ It is somehow <u>more probable</u> for photons to go to some areas and <u>less probable</u> for them to go to other areas