CLICKER

So far:

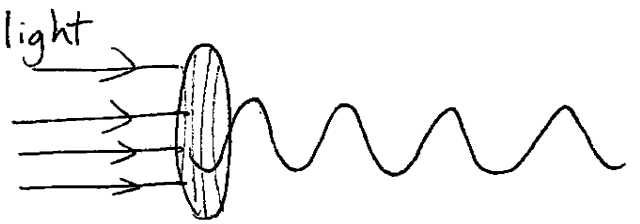
Light made of photons: discrete lumps of energy with $E = hf$

BUT: wave properties essential to explain many experiments → diffraction, interference, etc...

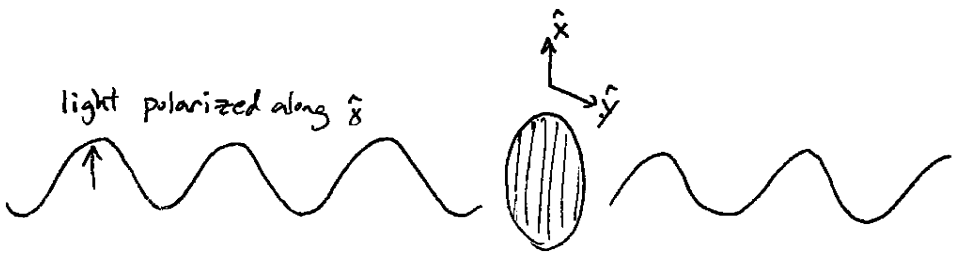
★ How can photons have both wave & particle properties? ★

Simple example: polarization experiments

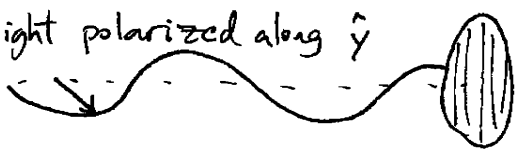
POLARIZATION SLIDE



polarizer: allows only component of light with $\vec{E}$ aligned with polarizer.

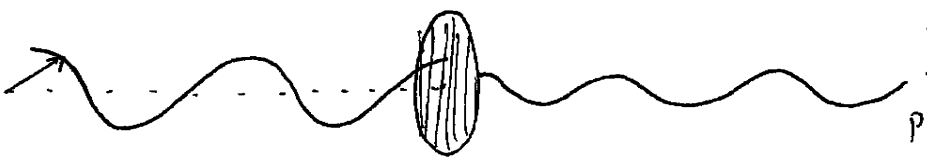


all goes through.



none goes through

light polarized along 45° CLICKER

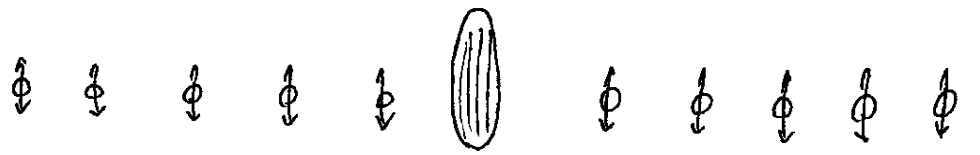


same wavelength.
$\frac{1}{2}$ intensity
transmitted light polarized along $\hat{x}$

Same results for very low intensity
∴ should be able to explain in terms of individual photons

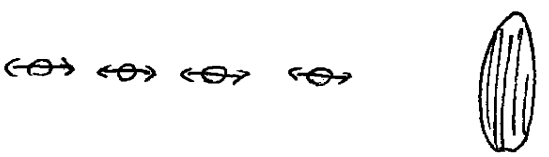
MODEL: each photon has a polarization.

∴ $\hat{x}$ polarization



all photons pass through.

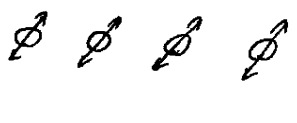
$\hat{y}$ polarization



none pass through.

∴ 45° polarization

CLICKER



same wavelength
∴ same energy / photon

half pass through.
(random distribution like flipping a coin)
YNNYYNYNNNYYY

→ 45° photons pass through polarizer with 50% probability.

Cannot predict what will happen, even with complete knowledge of initial state.

Only probability can be predicted!