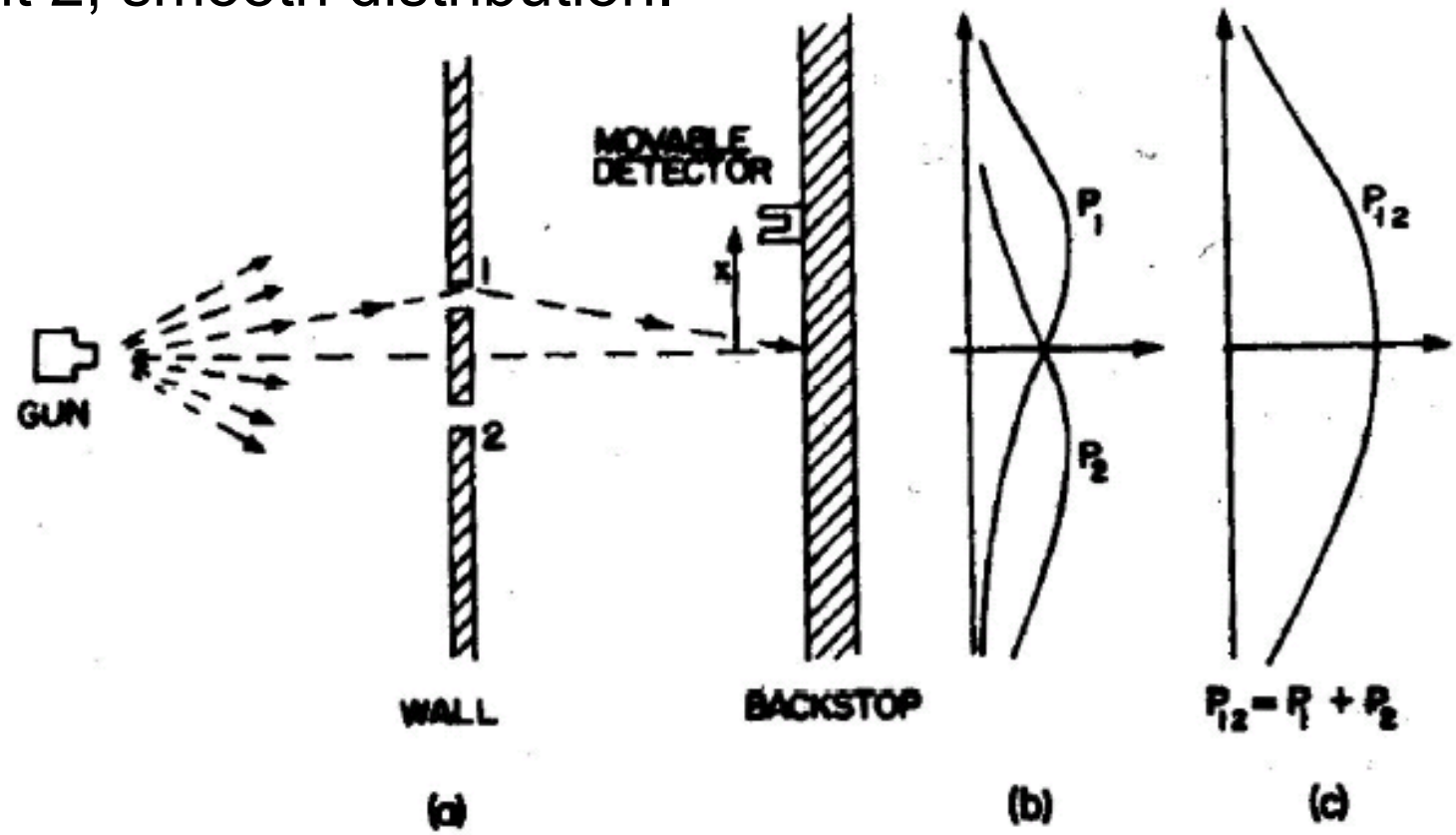
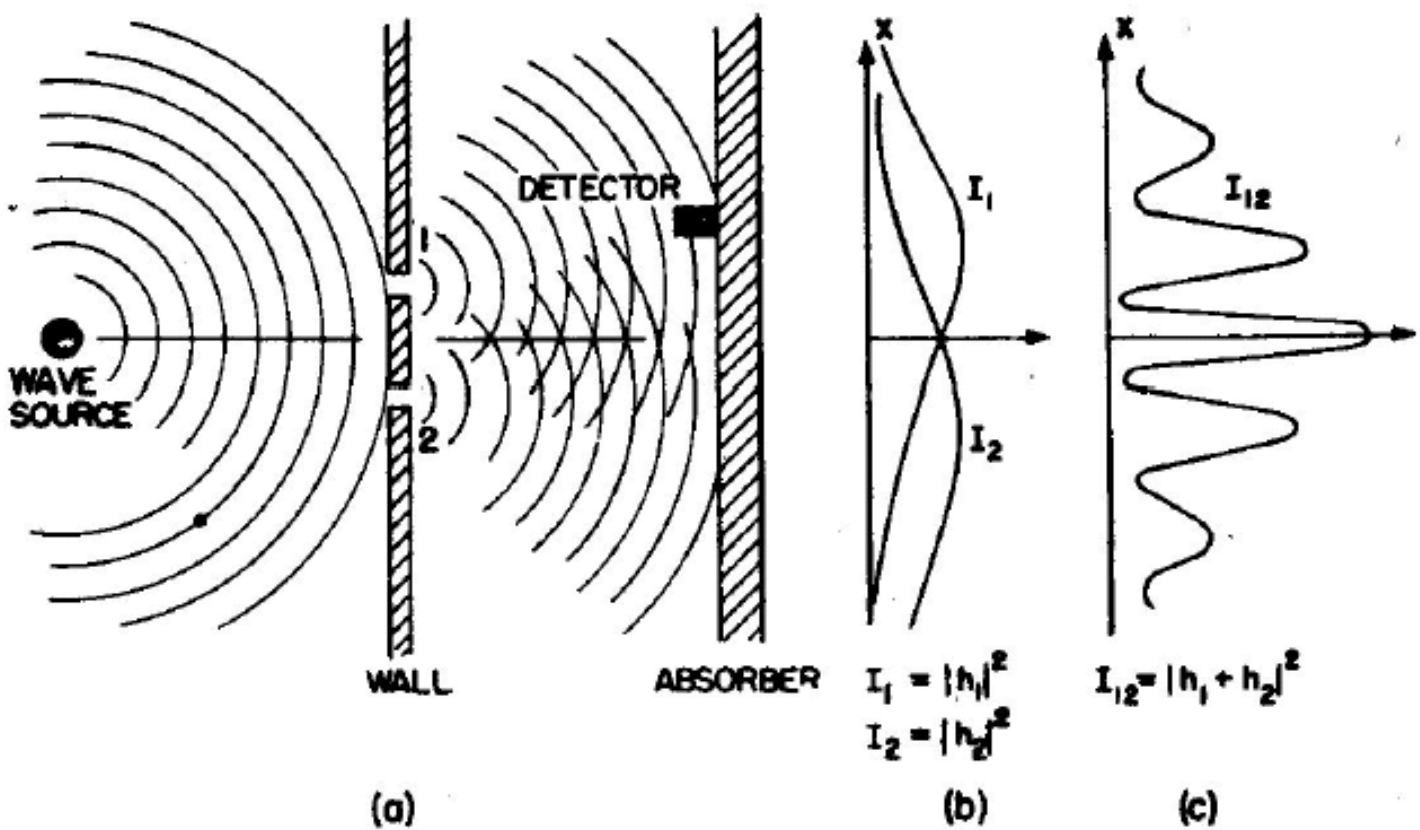
2-slit experiments with bullets (classical particles)

- Bullets always come in "lumps" -- identical size, mass particles.
- No interference: probability to arrive at screen is sum of probability to go through slit 1 and probability to go through slit 2, smooth distribution.



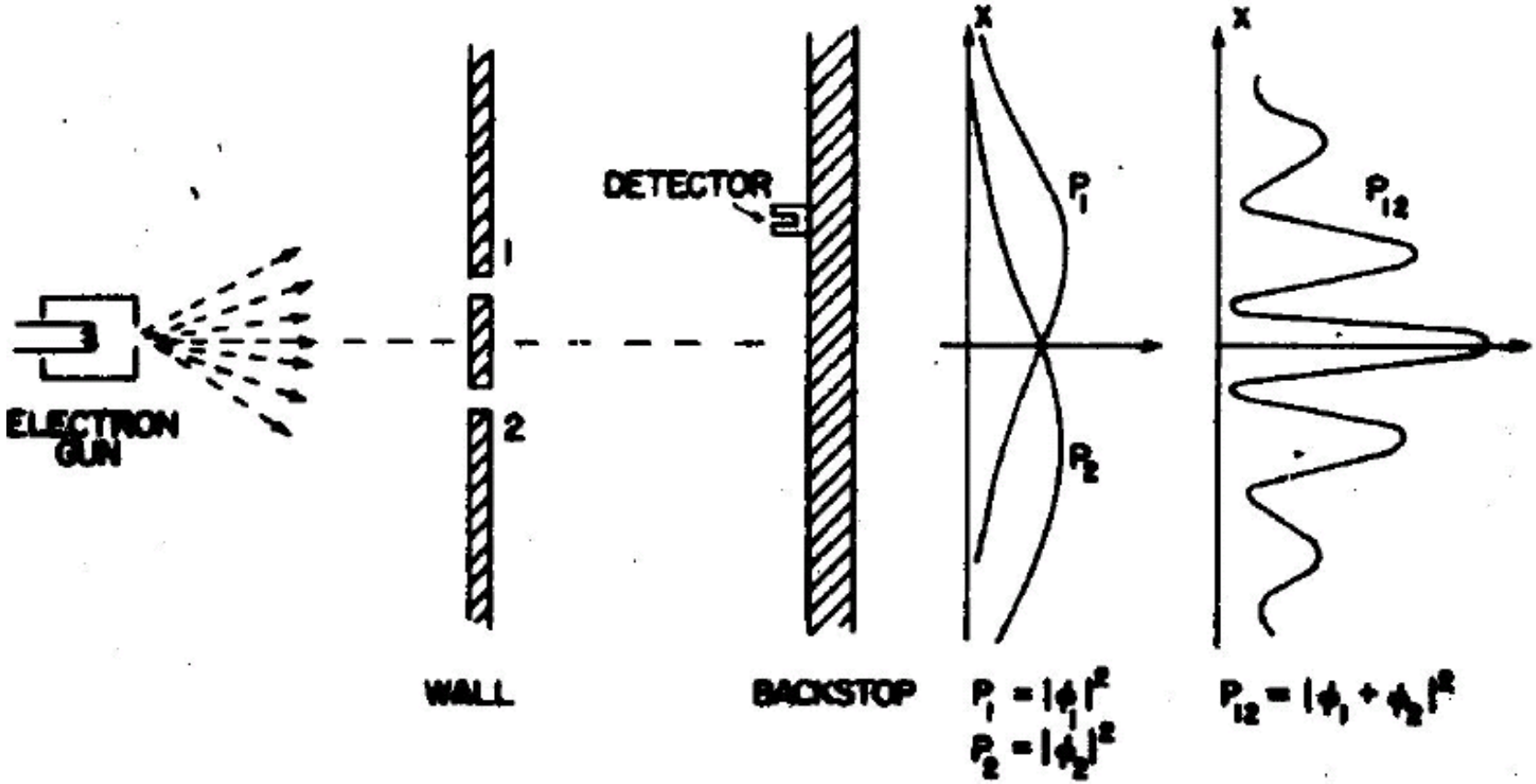
2-slit experiments with water (classical waves)

- Intensity of water waves propotional to height^2
- Intensity of waves reaching detector through slit 2 when slit 1 is closed is smooth, and vice versa.
- When two waves are allowed to pass through 1 and 2 at same time, interference pattern is created.



2-slit experiments with electrons (do they behave like bullets or waves?)

- Interference pattern observed by detector at screen



$\phi = \psi$ = Schroedinger's wave function!

So--electrons are waves?

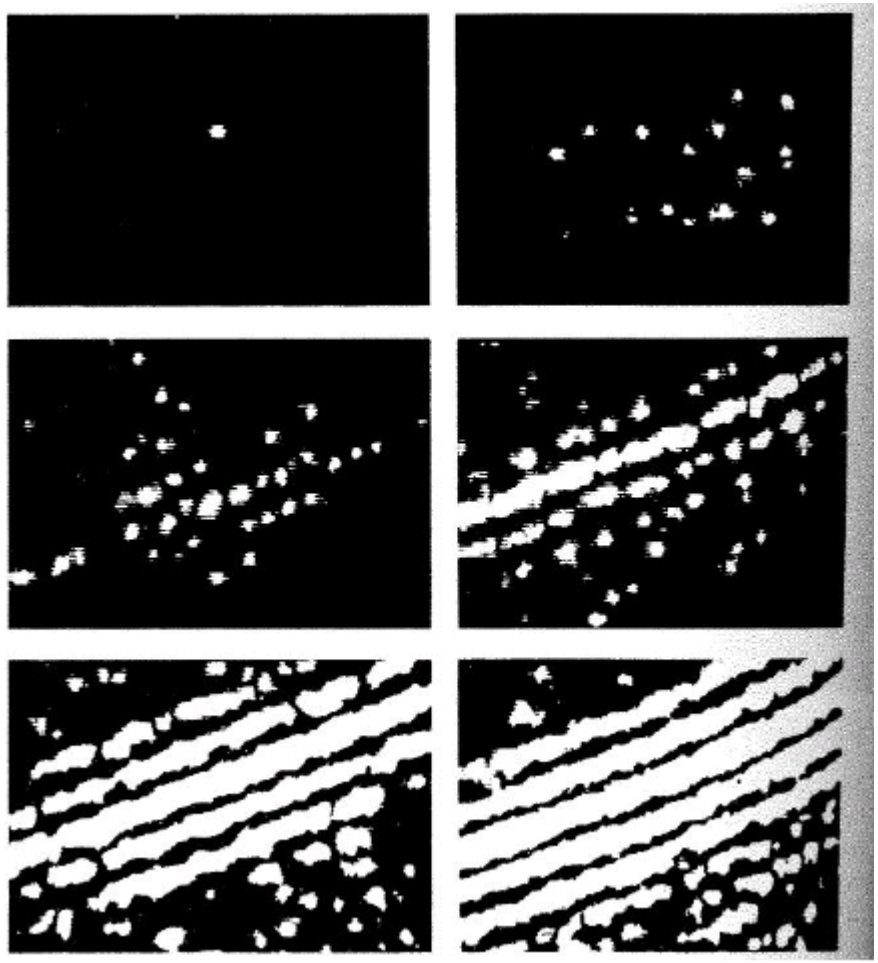
- Wait--we can slow gun down so that only 1 electron per hour goes through. Then we expect electron goes through slit 1 or 2, right? Every hour we get a new spot on the screen.
- Interference pattern builds up slowly:

So: electrons are "particle-waves"!

They exhibit properties of classical waves *and* particles

2-slit experiments with light

Weaken laser beam so that very few photons come out!

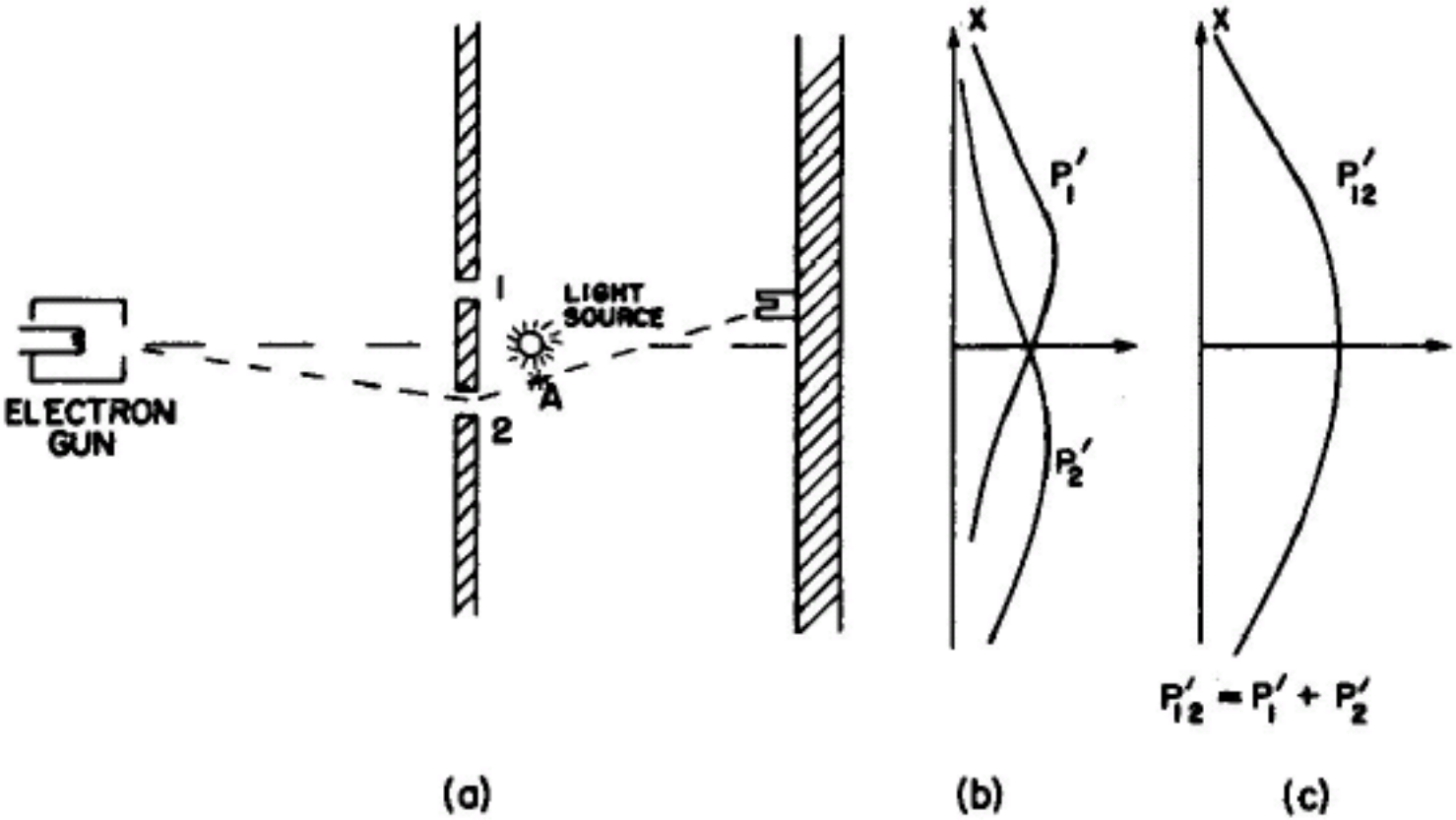


Light is "particle-wave" just like electrons!

(except photons move at speed of light, have no mass)

Observing which slit electrons go through I)

Wait a minute: if electrons can be seen to go through one slit or the other, how can they interfere with themselves? Let's try to determine which slit they pass through with a "camera"



Act of observation destroys interference pattern!

One way to say this: pinning down particle's position made momentum indeterminate!

Heisenberg uncertainty principle:

$$\Delta x \, \Delta p \approx \hbar$$

Planck's const. divided by 2π

uncertainty in your measurement of particle's *position*

uncertainty in your measurement of particle's *momentum*

Observing which slit electrons go through II)

Wait another minute! Maybe the light we used to observe the electron bumped it somehow, destroying interference. How about if we reduce the light's intensity or frequency?

• Reduce intensity: sometimes electron isn't observed--then it contributes to interference!

• Reduce frequency: oops! Remember we said you can't resolve anything smaller than the wavelength of light? When wavelength gets bigger than distance between slits, interference pattern comes back! Heisenberg again.

Conclusions:

● at small scales physics doesn't agree with our intuition. Rules of quantum mechanics predict results of all expts. so far, even if we have no "deeper" understanding.

● Particle is described by a "probability amplitude" to be somewhere.