Quàntica

La mecànica quàntica

Comportament de la matèria i la llum a escala atòmica (microscòpica)

Dualitat ona-partícula

No segueix la nostra intuició ordinària (física clàssica,
escala macroscòpica)

Un exemple: la **doble escletxa**

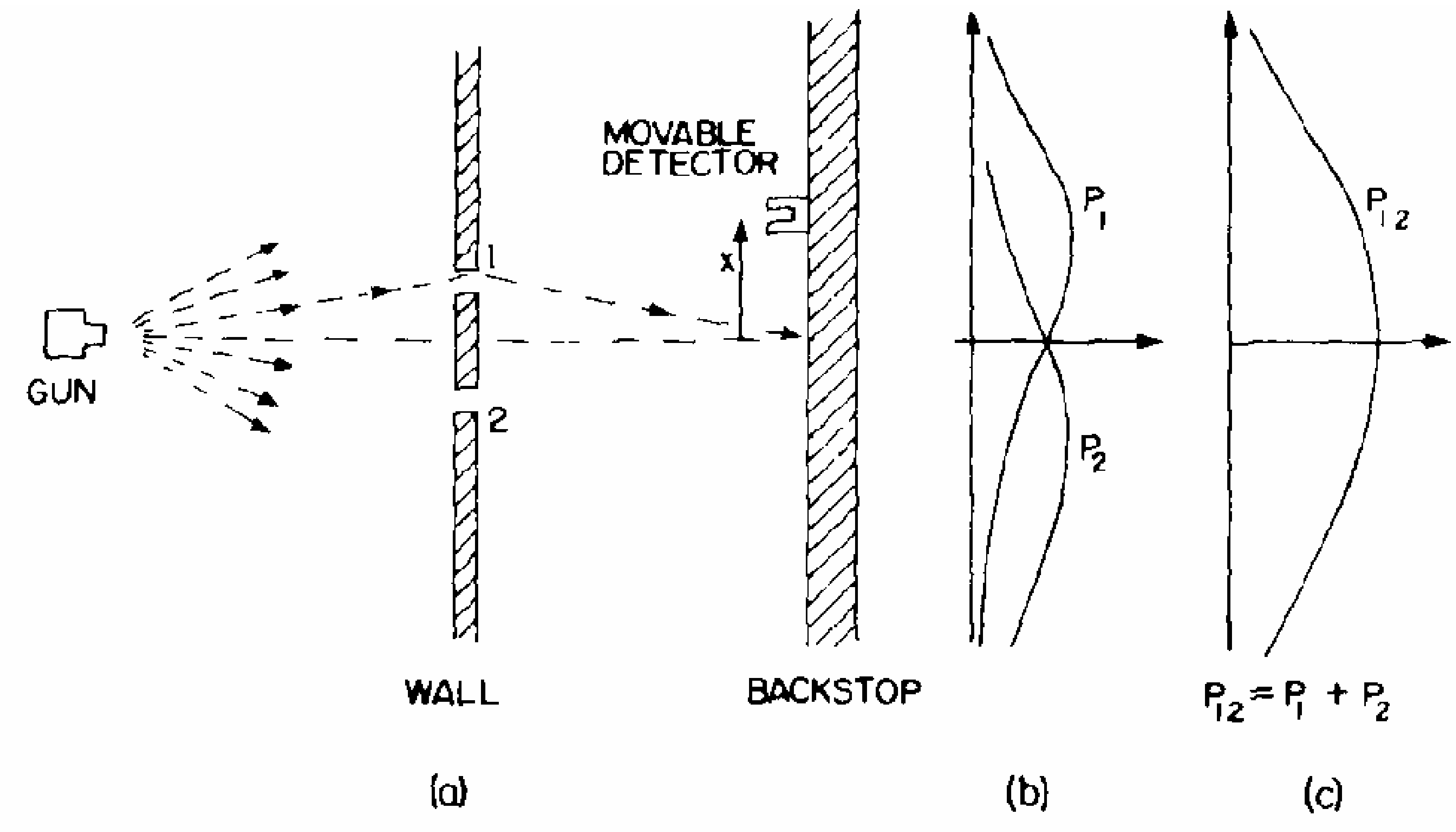
Paradigma del nou comportament misteriós

Impossible d'explicar clàssicament

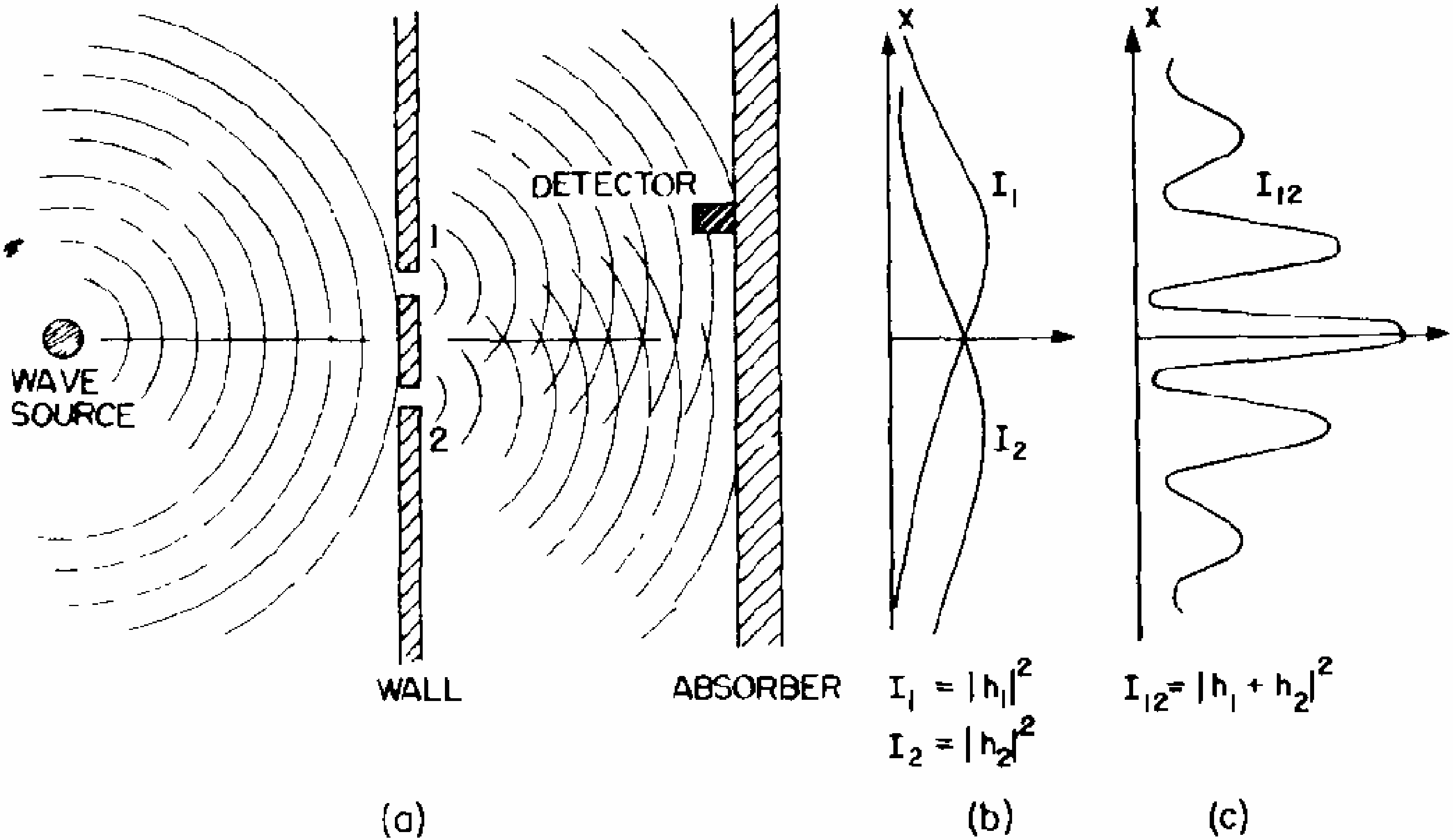
Referència: *The Feynman lectures on Physics*
R.P. Feynman, R.B. Leighton, M. Sands
Vol. III, Cap. 1

La doble escletxa

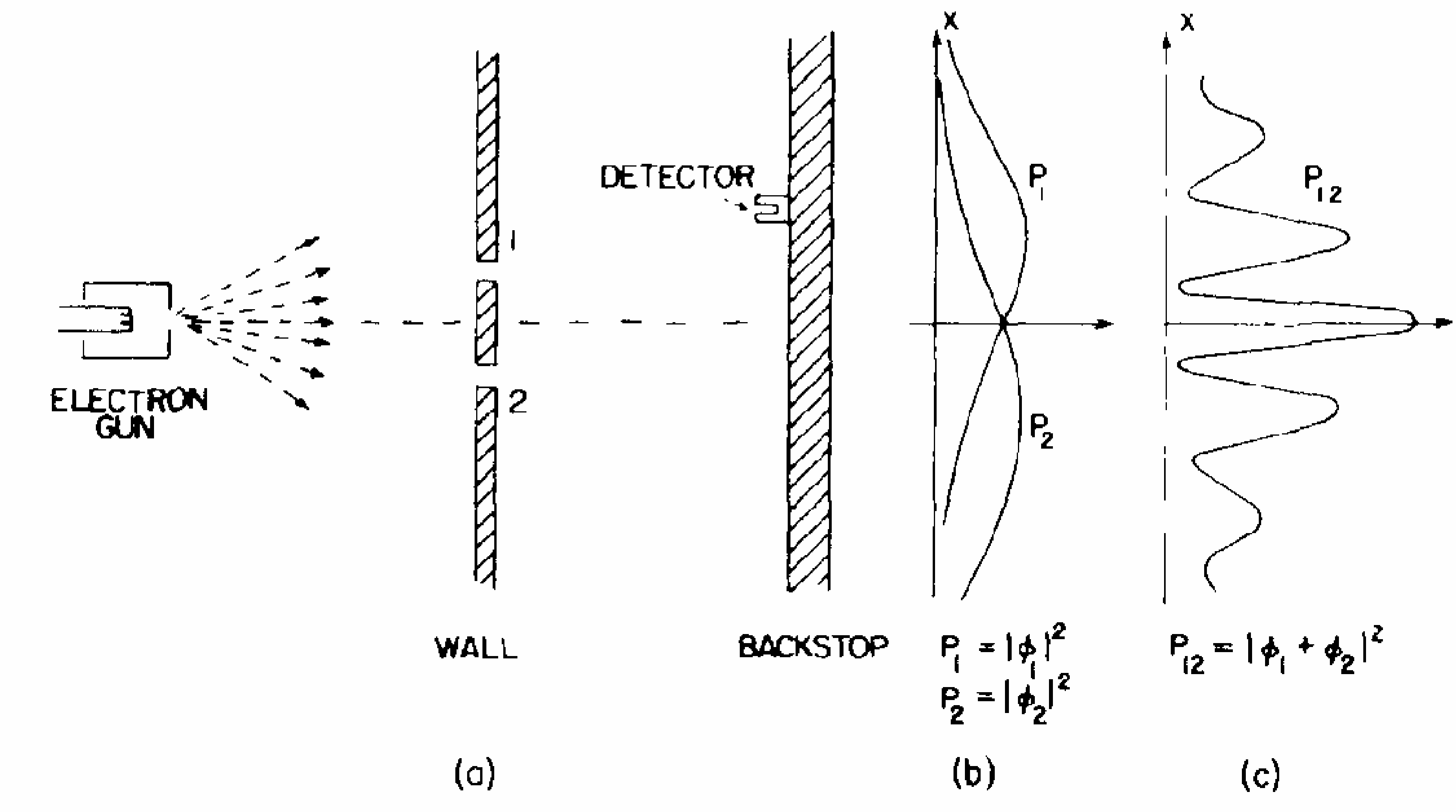
I. Un experiment amb “bales”



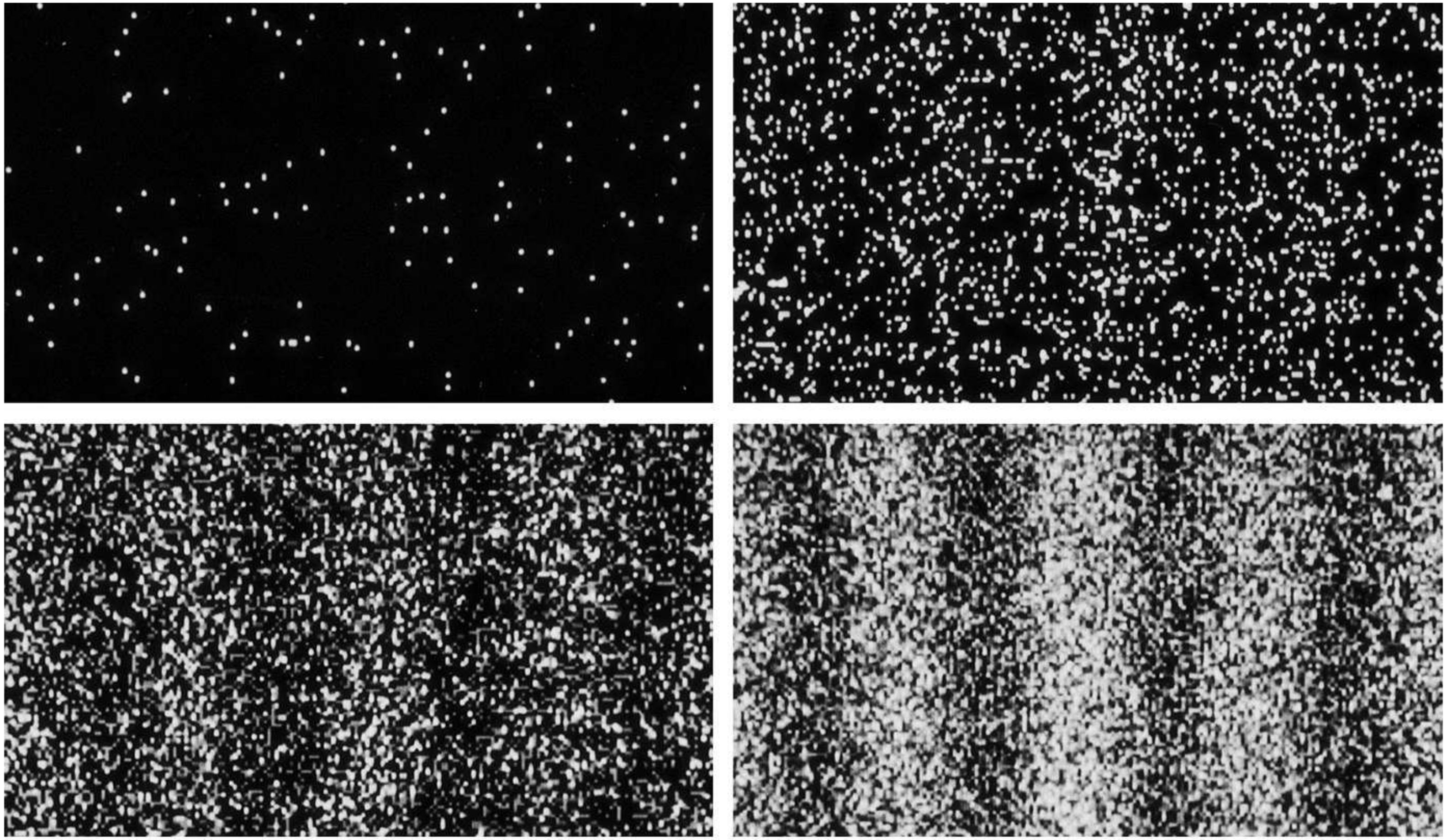
II. Un experiment amb "ones"



III. Un experiment amb electrons



Acumulació de ‘clicks’ del detector



Proposition A: Each electron *either* goes through hole 1 *or* it gocs through hole 2.

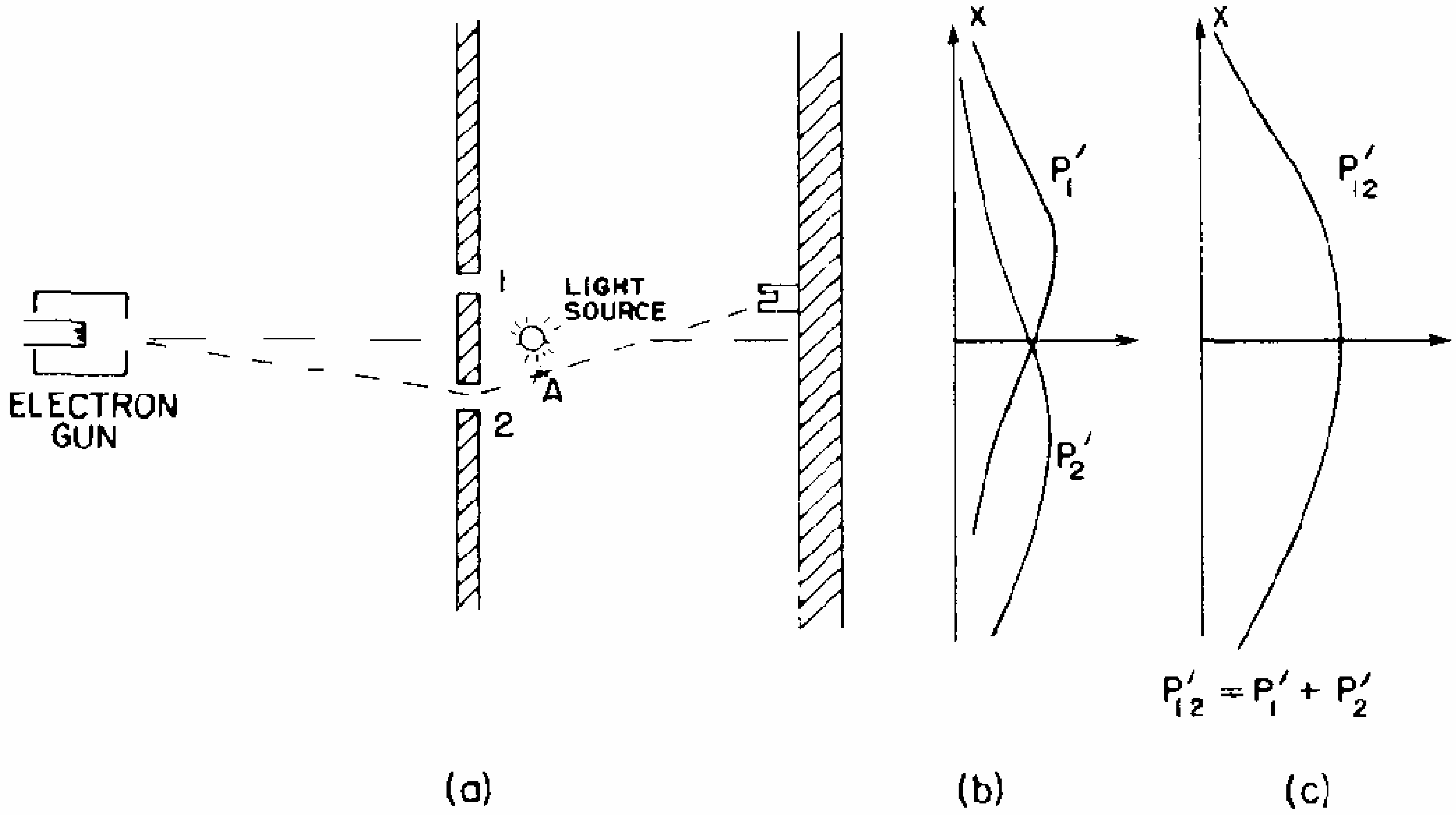
Això implicaria $P_{12} = P_1 + P_2$

We conclude the following: The electrons arrive in lumps, like particles, and the probability of arrival of these lumps is distributed like the distribution of intensity of a wave. It is in this sense that an electron behaves "sometimcs like a particle and sometimes like a wavc."

La proposició A és falsa.
Cada electró passa per les dues escletxes al mateix temps!

Si, però, els podem veure passar per les dues escletxes?

Observant els electrons quan passen



We must conclude that *when we look at the electrons* the distribution of them on the screen is different than when we do not look. Perhaps it is turning on our light source that disturbs things? It must be that the electrons are very delicate, and the light, when it scatters off the electrons, gives them a jolt that changes their ...

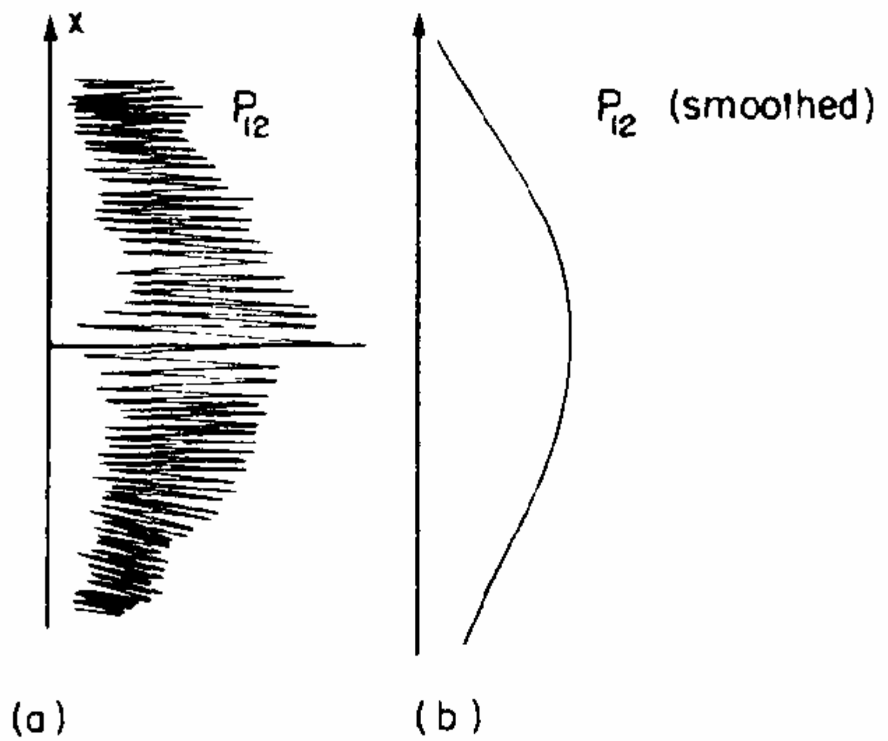


Fig. 1–5. Interference pattern with bullets: (a) actual (schematic), (b) observed.

SUMMARY

(1) The probability of an event in an ideal experiment is given by the square of the absolute value of a complex number ϕ which is called the probability amplitude:

$$P = \text{probability},$$
$$\phi = \text{probability amplitude}, \tag{1.6}$$
$$P = |\phi|^2$$

(2) When an event can occur in several alternative ways, the probability amplitude for the event is the sum of the probability amplitudes for each way considered separately. There is interference:

$$\phi = \phi_1 + \phi_2,$$
$$P = |\phi_1 + \phi_2|^2 \tag{1.7}$$

(3) If an experiment is performed which is capable of determining whether one or another alternative is actually taken, the probability of the event is the sum of the probabilities for each alternative. The interference is lost:

$$P = P_1 + P_2. \tag{1.8}$$

One might still like to ask: "How does it work? What is the machinery behind the law?" No one has found any machinery behind the law. No one can "explain" any more than we have just "explained." No one will give you any deeper representation of the situation. We have no ideas about a more basic mechanism from which these results can be deduced.

physics has given up on the problem of trying to predict exactly what will happen in a definite circumstance. Yes! physics *has* given up. *We do not know how to predict what would happen in a given circumstance*, and we believe now that it is impossible—that the only thing that can be predicted is the probability of different events. It must be recognized that this is a retrenchment in our earlier ideal of understanding nature. It may be a backward step, but no one has seen a way to avoid it.

El principi d'incertesa de Heisenberg

The uncertainties in the position and momentum of a particle at any instant must have their product greater than Planck's constant. This is a special case of the uncertainty principle that was stated above more generally. The more general statement was that one cannot design equipment in any way to determine which of two alternatives is taken, without, at the same time, destroying the pattern of interference.

$$\Delta p$$

$$\Delta x \approx \frac{h}{\Delta p}$$

$$h = 6.63 \times 10^{-34}\ \mathrm{Js}$$

Constant de Planck

$$\Delta x \Delta p > h$$

El principi de Heisenberg "protegeix" la Mecànica Quàntica de tota inconsistència o contradicció

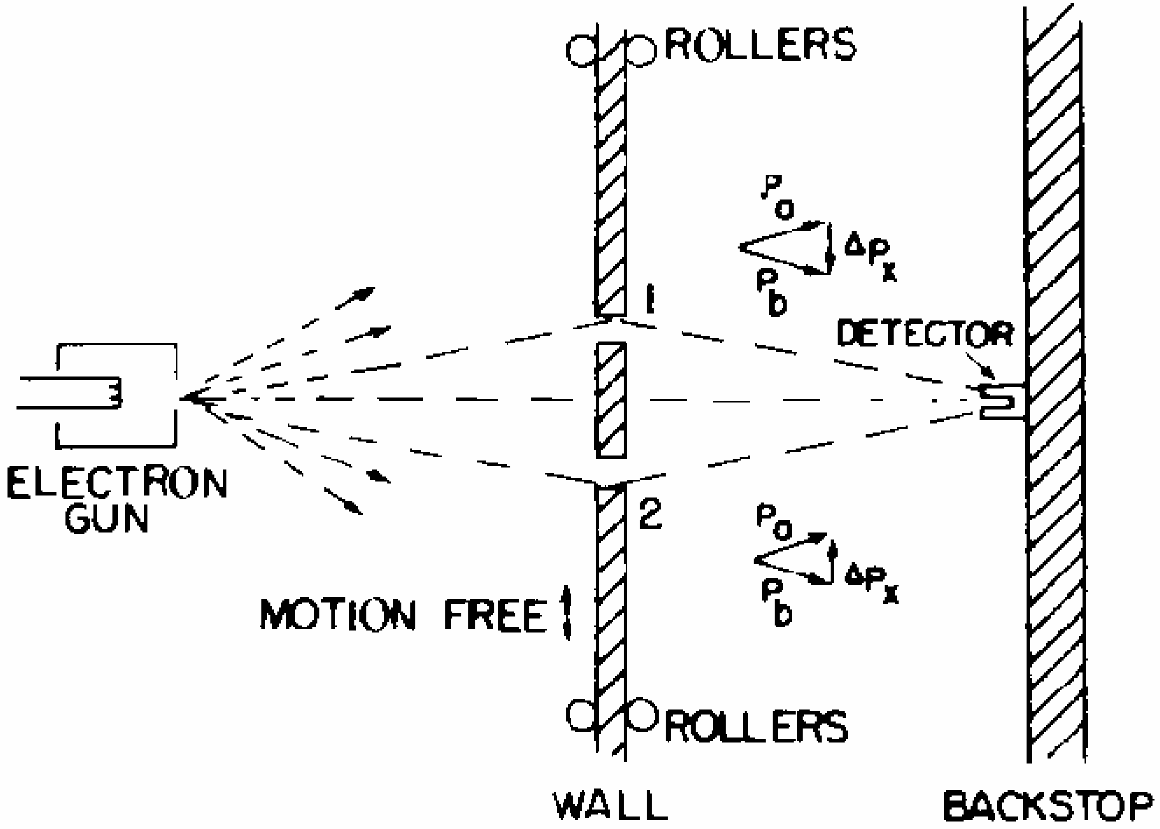
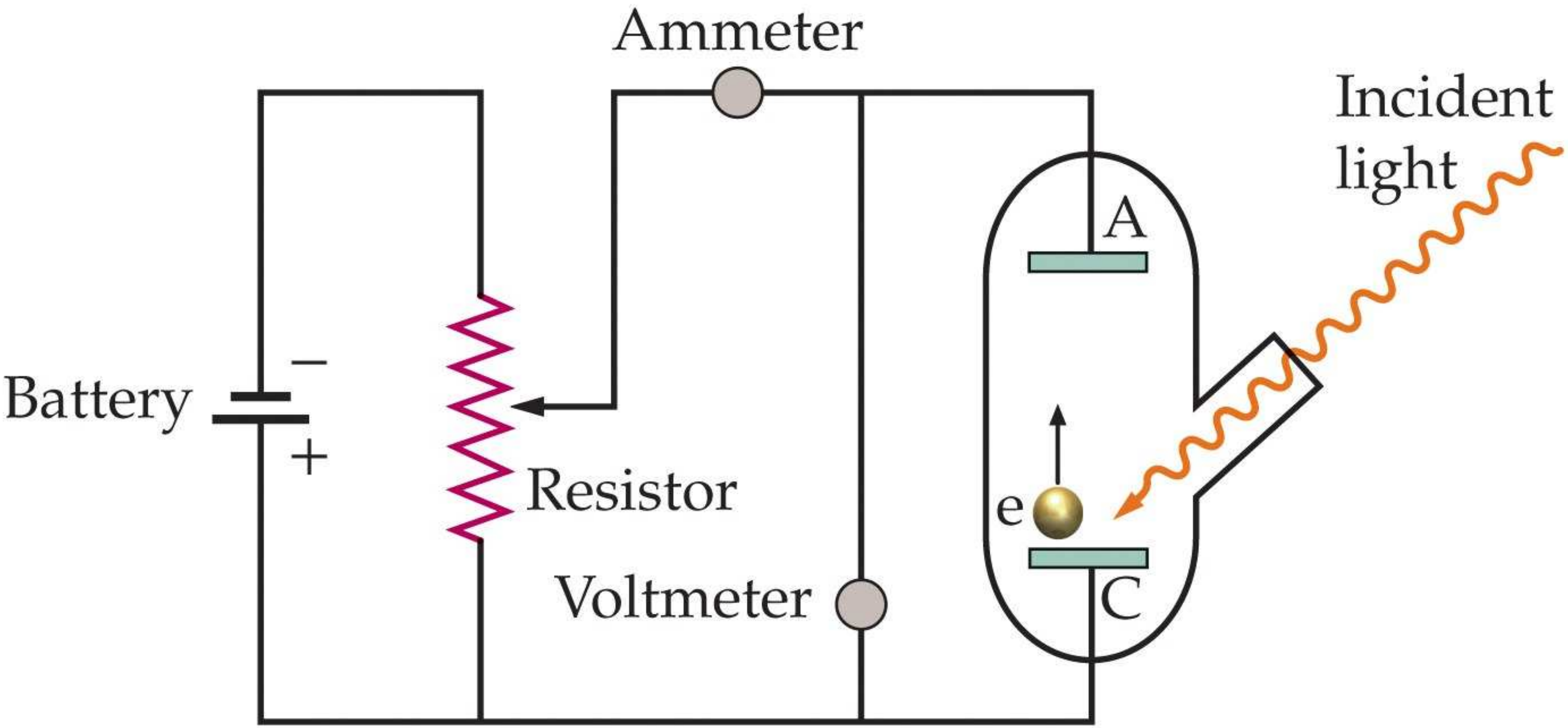


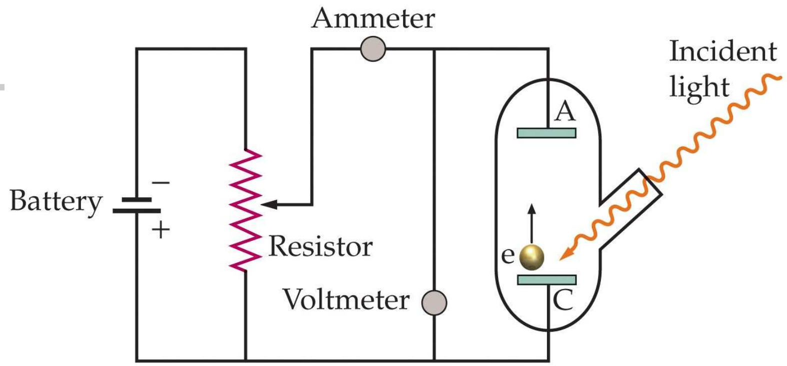
Fig. 1–6. An experiment in which the recoil of the wall is measured.

L'efecte fotoelèctric

Einstein 1905 Existència dels fotons

La constant de Planck



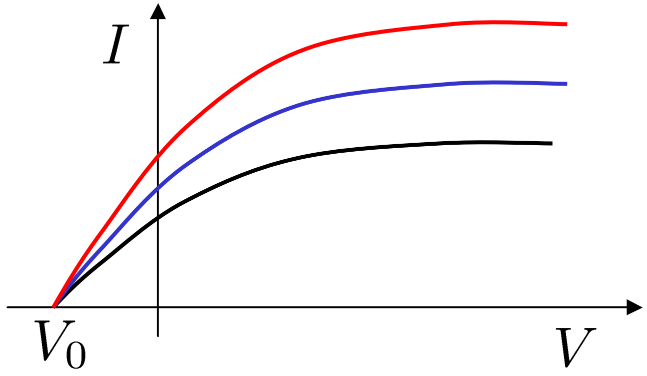


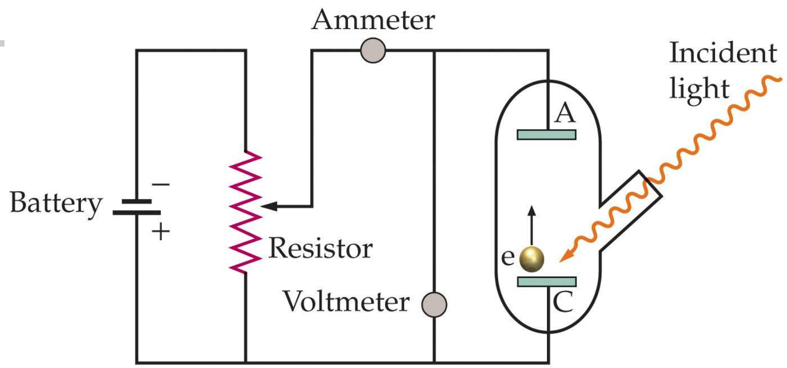
$$E = hf = \frac{hc}{\lambda} \qquad 34\text{-}1$$

EINSTEIN EQUATION FOR PHOTON ENERGY

$$h = 6.63 \times 10^{-34}\ \text{Js} = 4.14 \times 10^{-15}\ \text{eVs}$$

Constant de Planck





a) The number of electrons emitted is proportional to the intensity of the incident radiation.

b) For each metal there is a threshold frequency ν_0, such that for radiation of frequency $\nu < \nu_0$ no electrons are emitted.

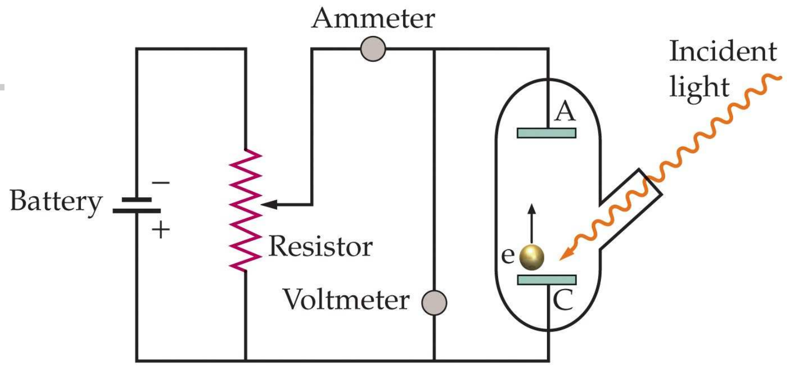
c) The maximum kinetic energy of the emitted electrons is proportional to $(\nu - \nu_0)$ and is independent of the intensity of the incident radiation.

d) The emission of electrons is practically instantaneous, appearing and disappearing with the EM radiation without measurable delay.

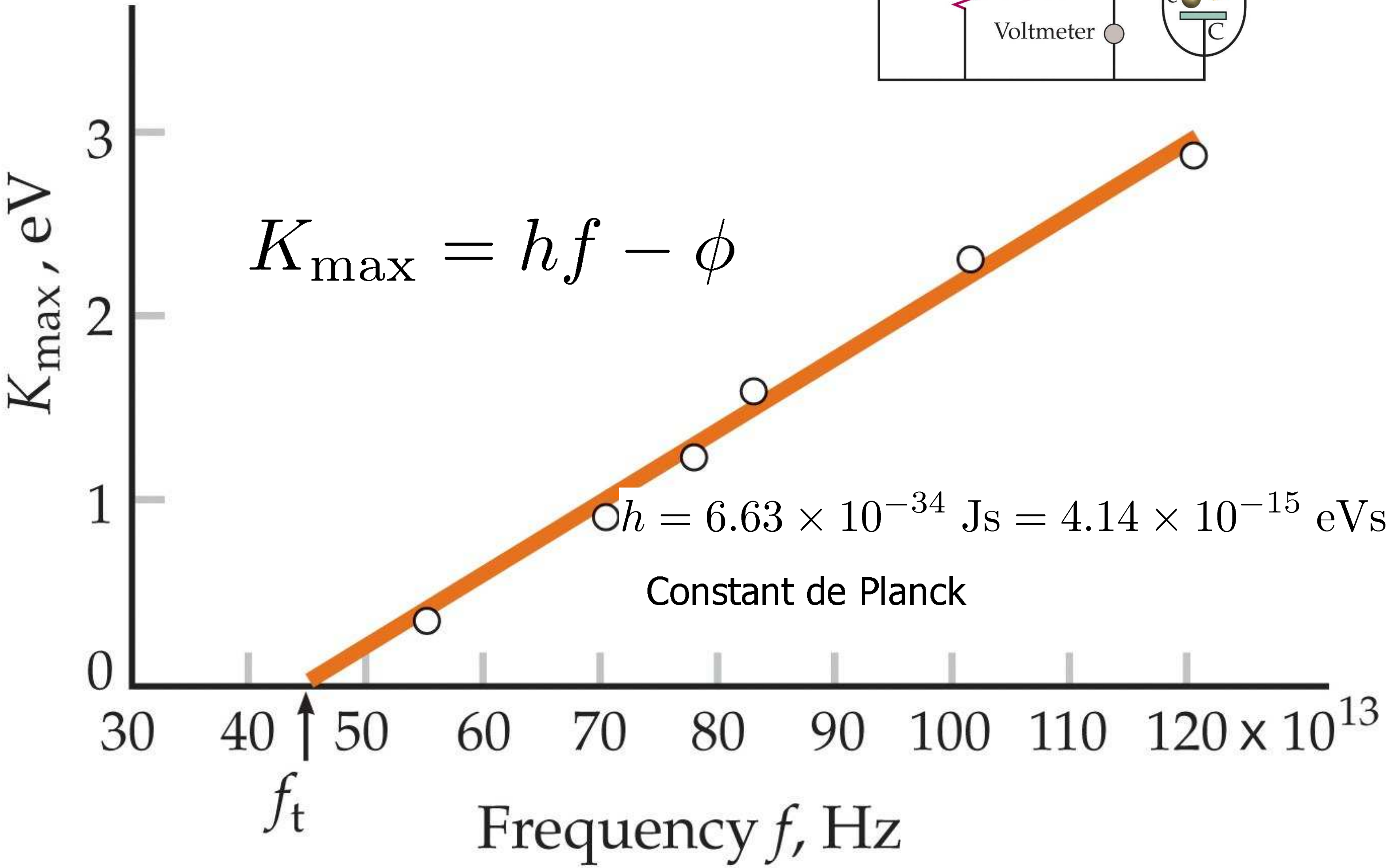
$$eV_0 = K_{\text{max}}$$

$$K_{\text{max}} = \left(\tfrac{1}{2}mv^2\right)_{\text{max}} = hf - \phi \qquad 34\text{-}3$$

EINSTEIN'S PHOTOELECTRIC EQUATION



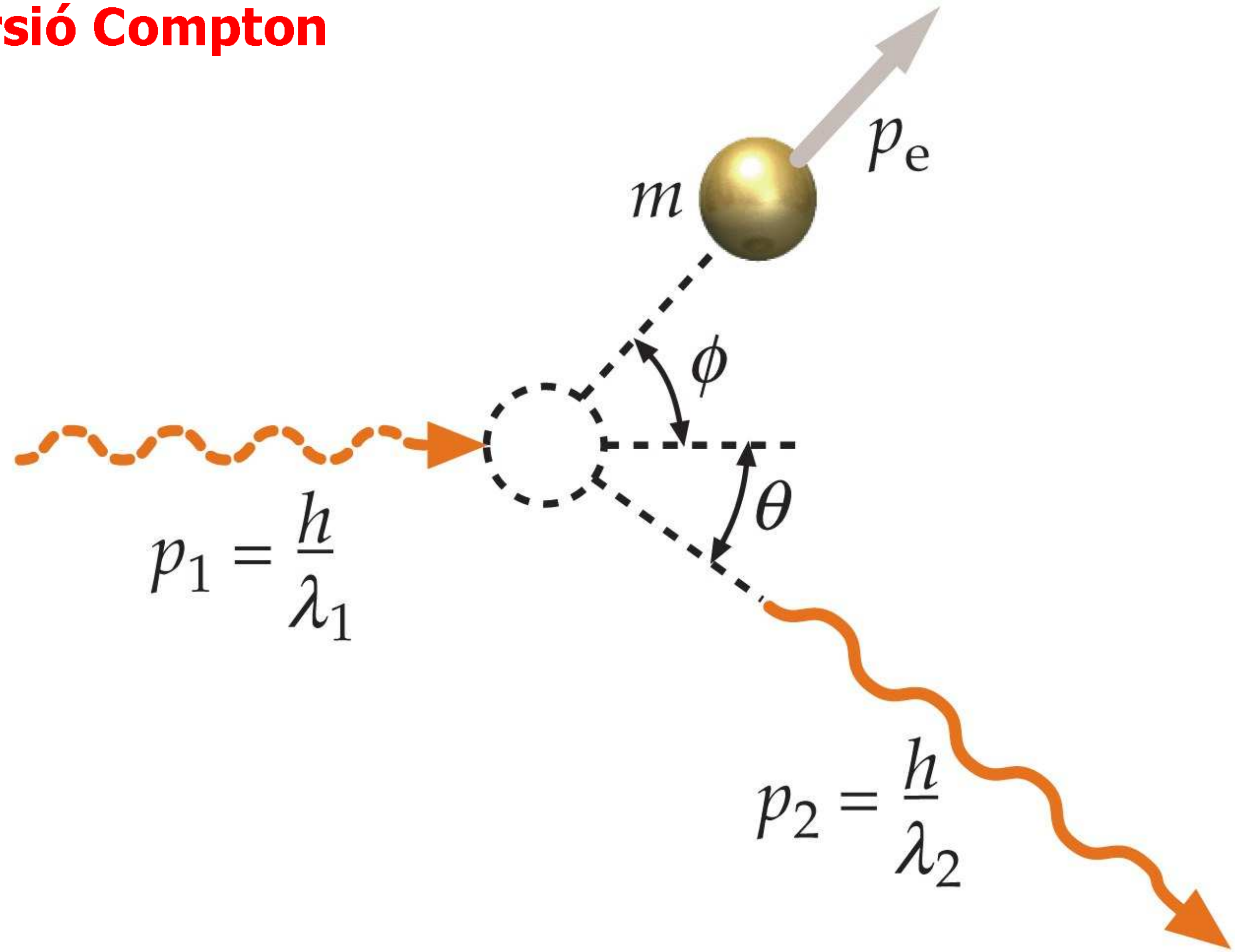
$$K_{\max} = hf - \phi$$



$$h = 6.63 \times 10^{-34}\ \mathrm{Js} = 4.14 \times 10^{-15}\ \mathrm{eVs}$$

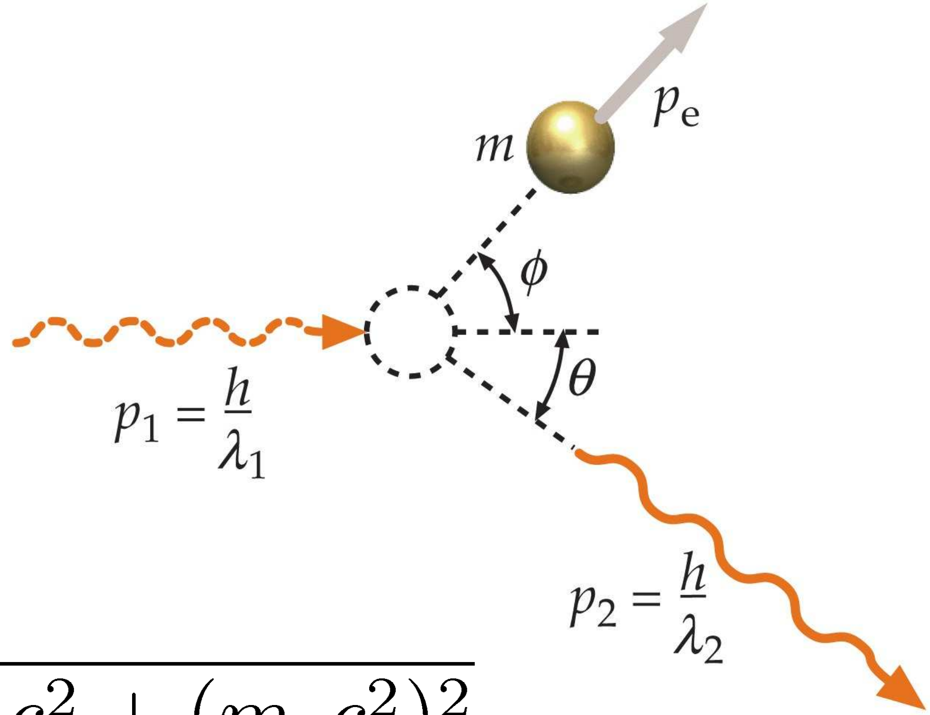
Constant de Planck

La dispersió Compton



$$\lambda_2 - \lambda_1 = \frac{h}{m_e c}(1 - \cos\theta) \qquad 34\text{-}11$$

COMPTON EQUATION



$$\vec{p}_1 = \vec{p}_2 + \vec{p}_e$$

$$p_1 c + m_e c^2 = p_2 c + \sqrt{p_e^2 c^2 + (m_e c^2)^2}$$

$$p_e^2 = p_1^2 + p_2^2 - 2 p_1 p_2 \cos\theta$$

$$\frac{1}{p_2} - \frac{1}{p_1} = \frac{1}{m_e c}(1 - \cos\theta)$$

$$\lambda_2 - \lambda_1 = \frac{h}{m_e c}(1 - \cos\theta)$$

La hipòtesi de De Broglie

Comportament ondulatori de la matèria
Semblant a la llum
Doble escletxa

$$\lambda = \frac{h}{p}$$

$h = 6.63 \times 10^{-34}$ Js
Constant de Planck

Perquè al món macroscòpic no es veuen ones de matèria?

$$m = 170\,\mathrm{g} \qquad v = 100\,\frac{\mathrm{km}}{\mathrm{h}}$$

$$\lambda = \frac{h}{p} = 1.4 \times 10^{-34}\,\mathrm{m}$$

$$m = 10^{-6}\,\mathrm{g} \qquad v = 10^{-6}\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$\lambda = \frac{h}{p} = 6.63 \times 10^{-19}\,\mathrm{m}$$

Limit de baixes i altes (relativista) energies

$$E_c = \sqrt{p^2c^2 + m^2c^4} - mc^2$$

Baixa energia

$$E_c \ll mc^2 \Rightarrow E_c \approx \frac{p^2}{2m} \quad ; \quad p \approx \sqrt{2mE_c}$$

$$\lambda = \frac{h}{p} \approx \frac{hc}{\sqrt{2mc^2 E_c}}$$

Alta energia

$$E_c \gg mc^2 \Rightarrow E_c \approx pc \quad ; \quad p \approx \frac{E_c}{c}$$

$$\lambda = \frac{h}{p} \approx \frac{hc}{E_c}$$

$$hc = 1240 \text{ eVnm}$$

Electró $m_e c^2 = 0.511 \text{ MeV}$

Protó $m_p c^2 = 938 \text{ MeV} \approx 1 \text{ GeV}$

$$E_c = 50 \text{ eV}$$

$$\lambda_e = 0.173 \text{ nm}$$

$$\lambda_p = 0.004 \text{ nm}$$

$$E_c = 50 \text{ GeV}$$

$$\lambda_e = 0.2 \times 10^{-7} \text{ nm}$$

$$\lambda_p = 0.2 \times 10^{-7} \text{ nm}$$