Heisenberg

Werner Heisenberg
(1901-1976)

Uncertainty Principle

$$\Delta x \Delta p_x \geq \frac{\hbar}{2} \qquad \left(\Delta x \Delta k_x \geq \frac{1}{2} \right)$$

$$\Delta E \Delta t \geq \frac{\hbar}{2}$$

and more…

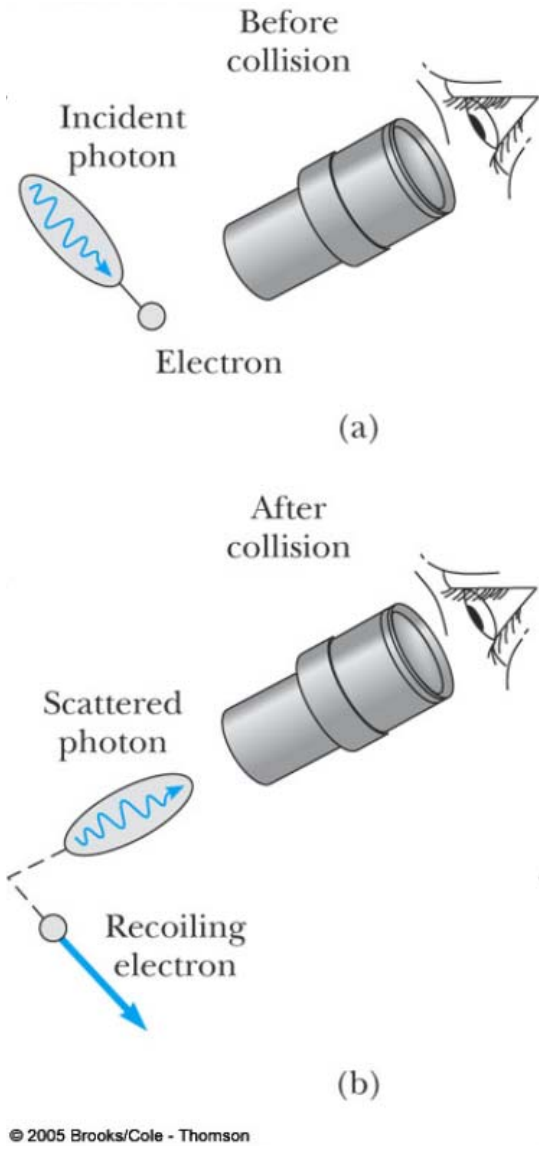
Before collision
Incident photon
Electron
(a)
After collision
Scattered photon
Recoiling electron
(b)
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Fig. 5-26, p. 176

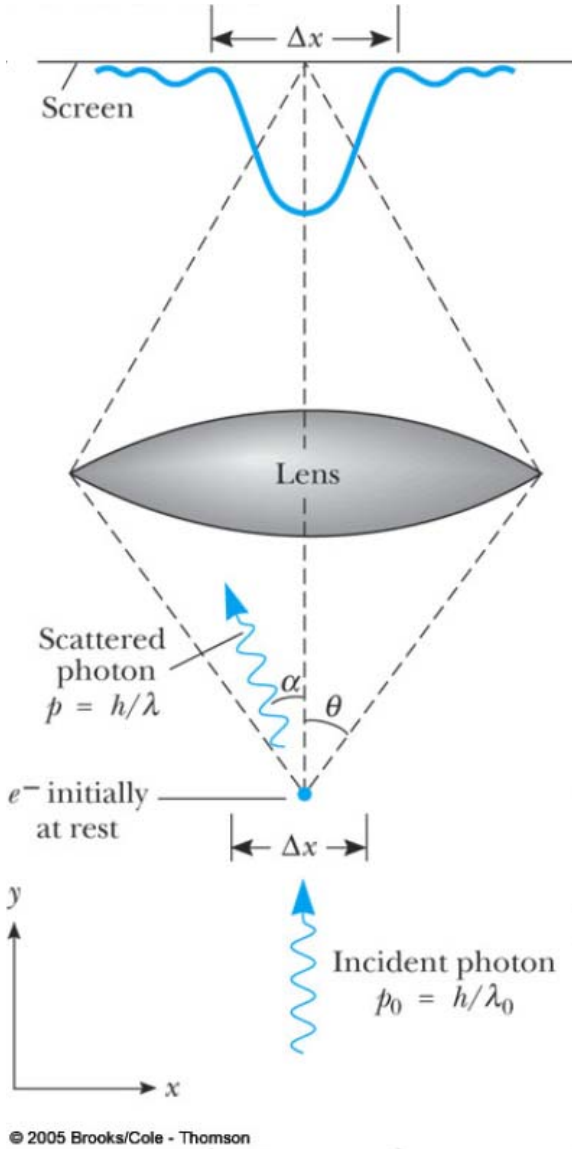
Δx
Screen
Lens
Scattered
photon
p = h/λ
α
θ
e⁻ initially
at rest
Δx
y
x
Incident photon
p₀ = h/λ₀
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Fig. 5-27, p. 176

Waves of What?

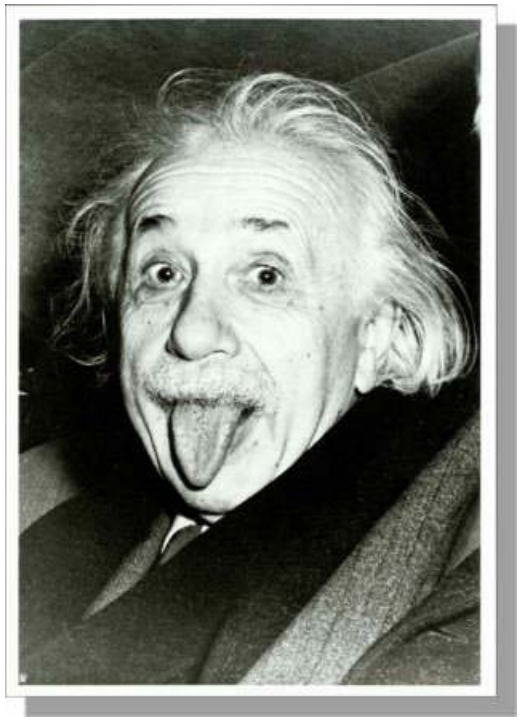
Max Born (1882-1970)

Waves of probability

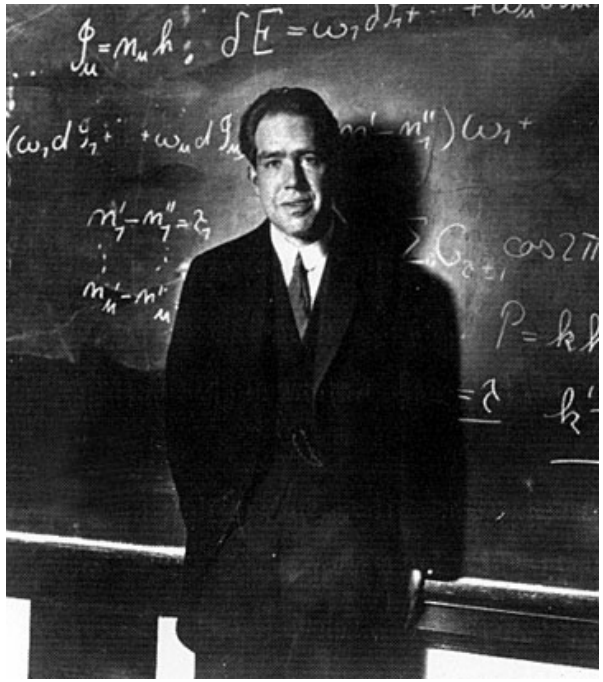
$|\Psi(x, y, z, t)|^2$ probability density function

Einstein vs. Bohr

"God does not play dice with the universe."



"Don't tell God what to do!"



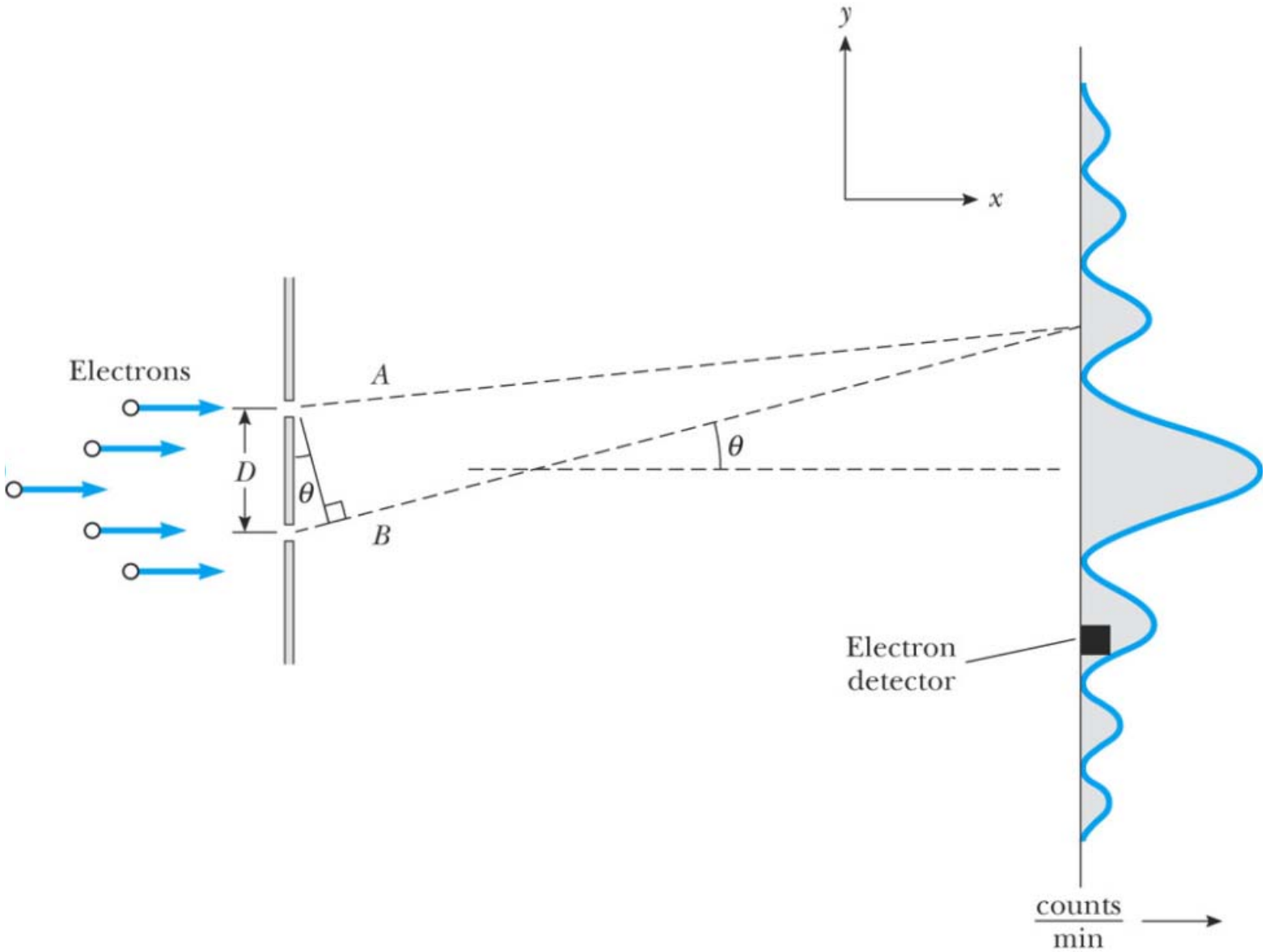


Fig. 5-28, p. 180

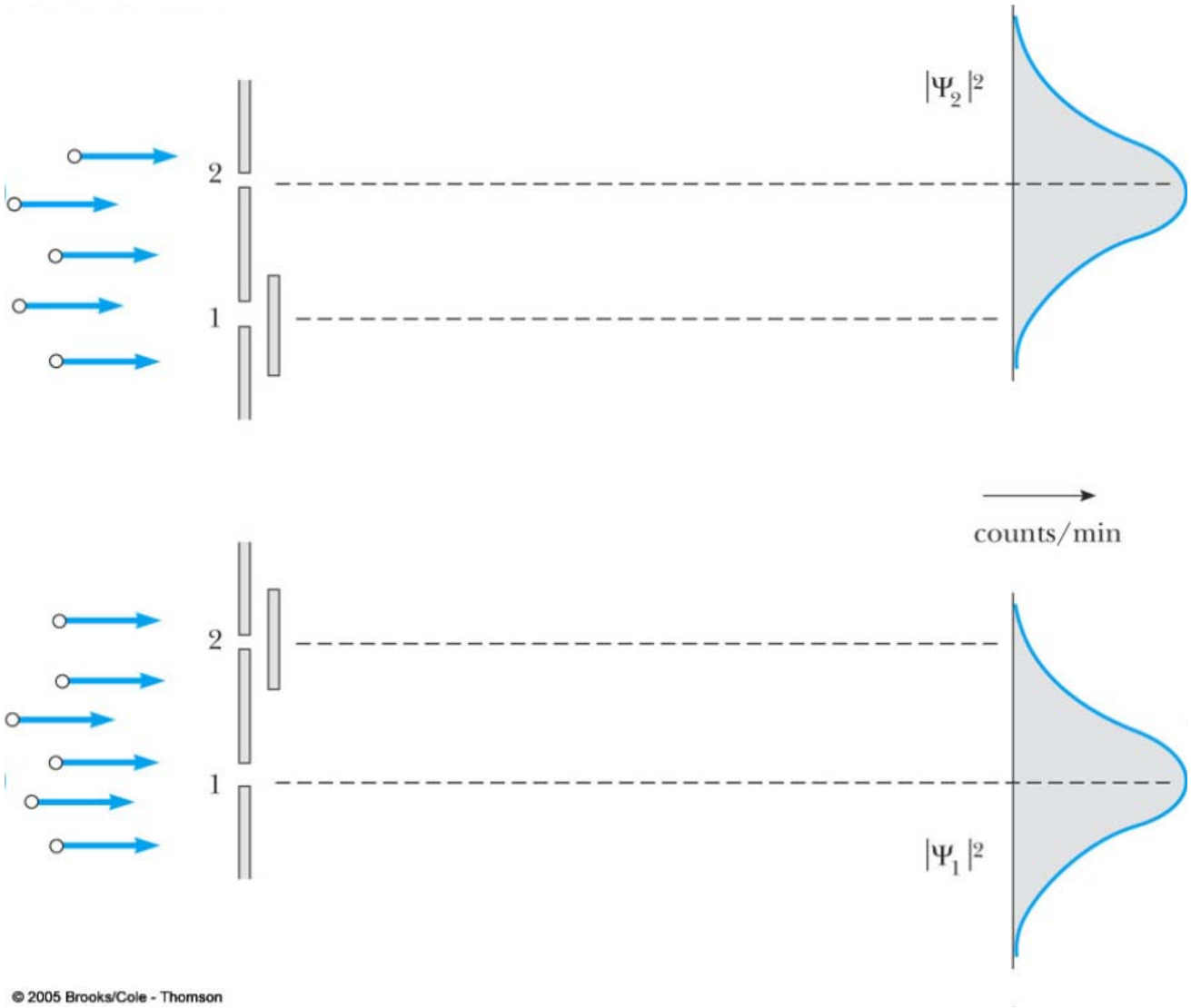


Fig. 5-30, p. 182

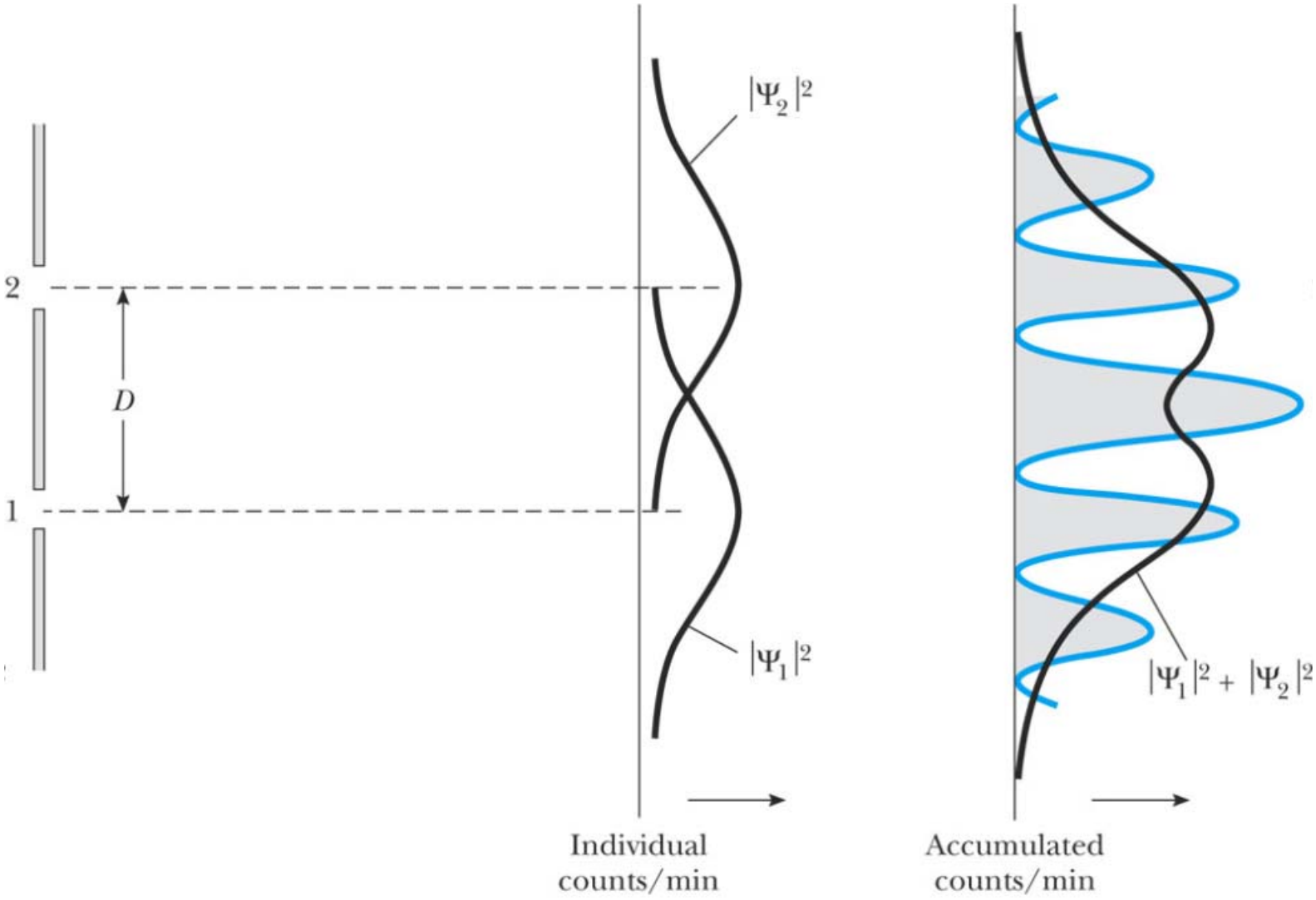


Fig. 5-31, p. 183

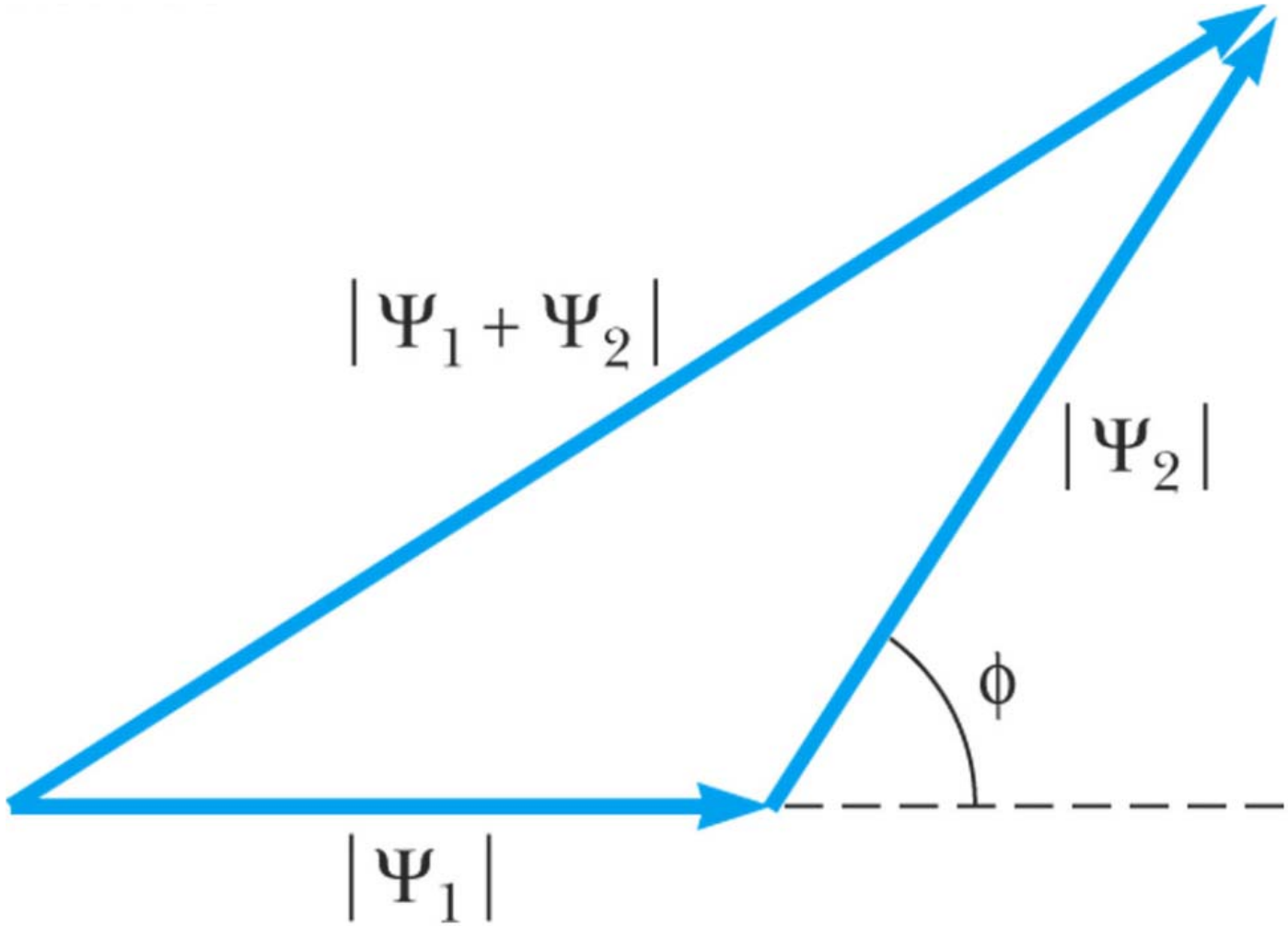


Fig. 5-32, p. 183

Table 5.1

Case	Wavefunction	Counts/Minute at Screen
Electron is measured to pass through slit 1 or slit 2	Ψ_1 or Ψ_2	$\lvert\Psi_1\rvert^2 + \lvert\Psi_2\rvert^2$
No measurements made on electron at slits	$\Psi_1 + \Psi_2$	$\lvert\Psi_1\rvert^2 + \lvert\Psi_2\rvert^2 + 2\lvert\Psi_1\rvert\lvert\Psi_2\rvert \cos\phi$

Table 5-1, p. 184

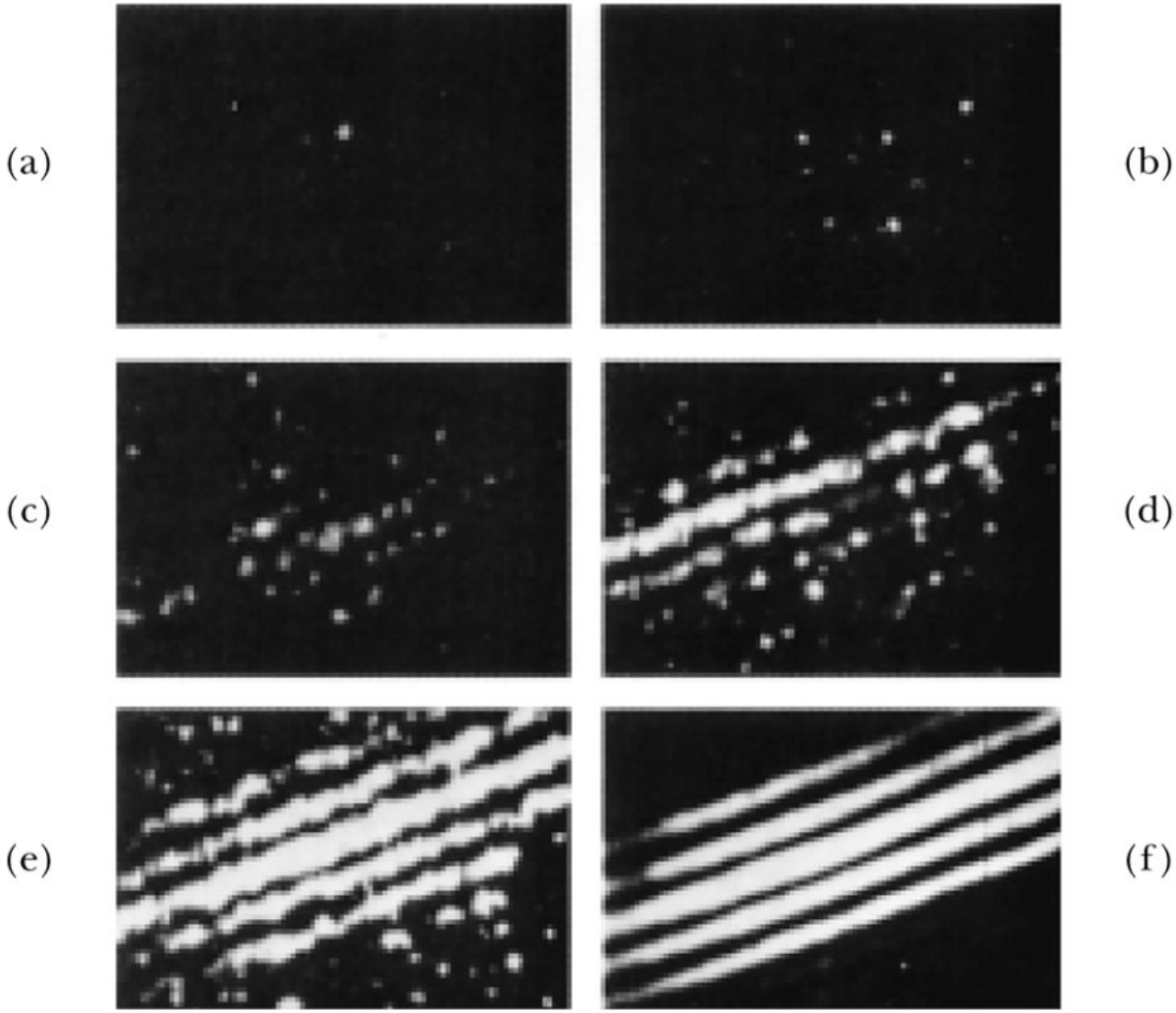


Fig. 5-29, p. 181

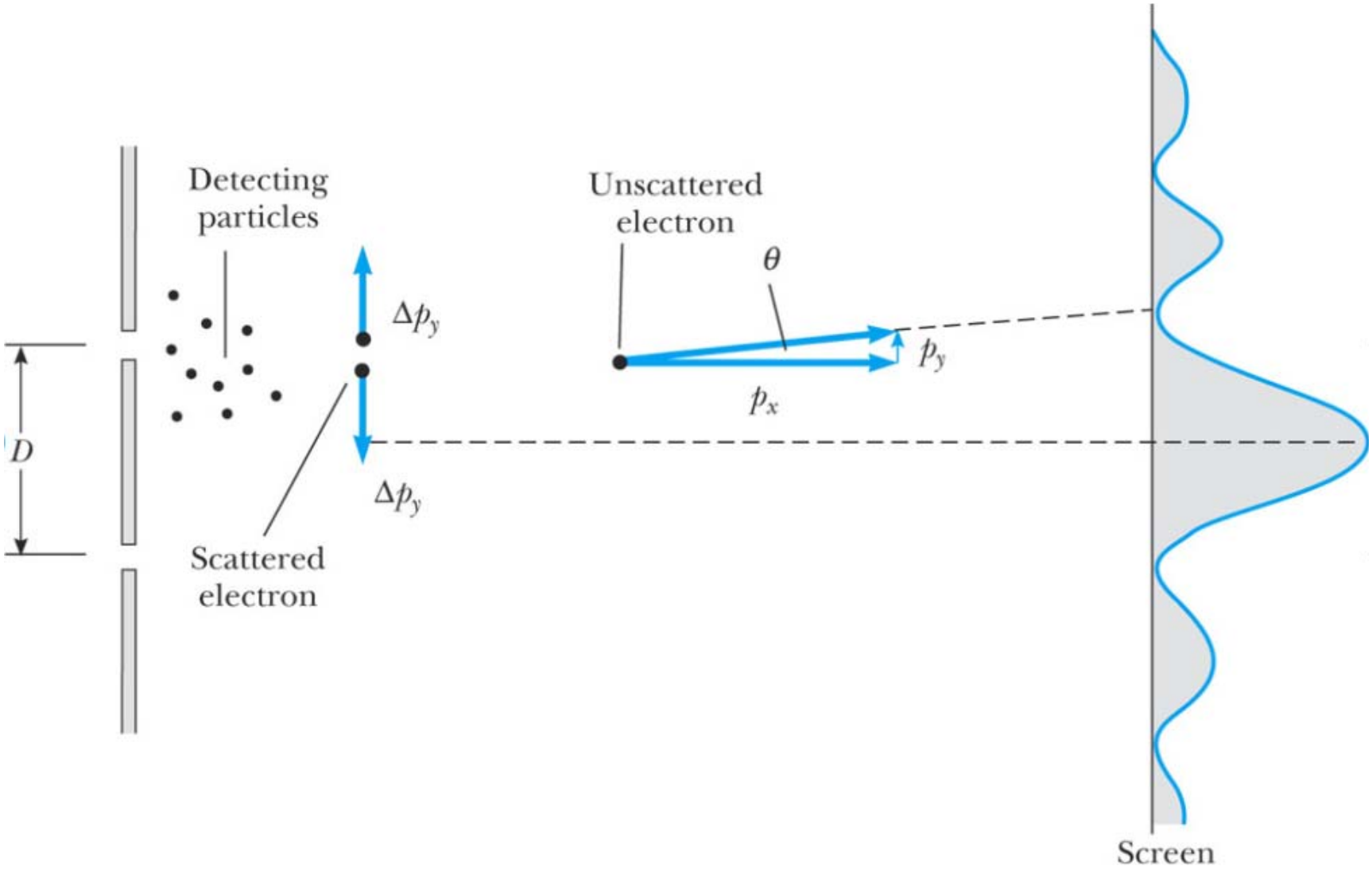
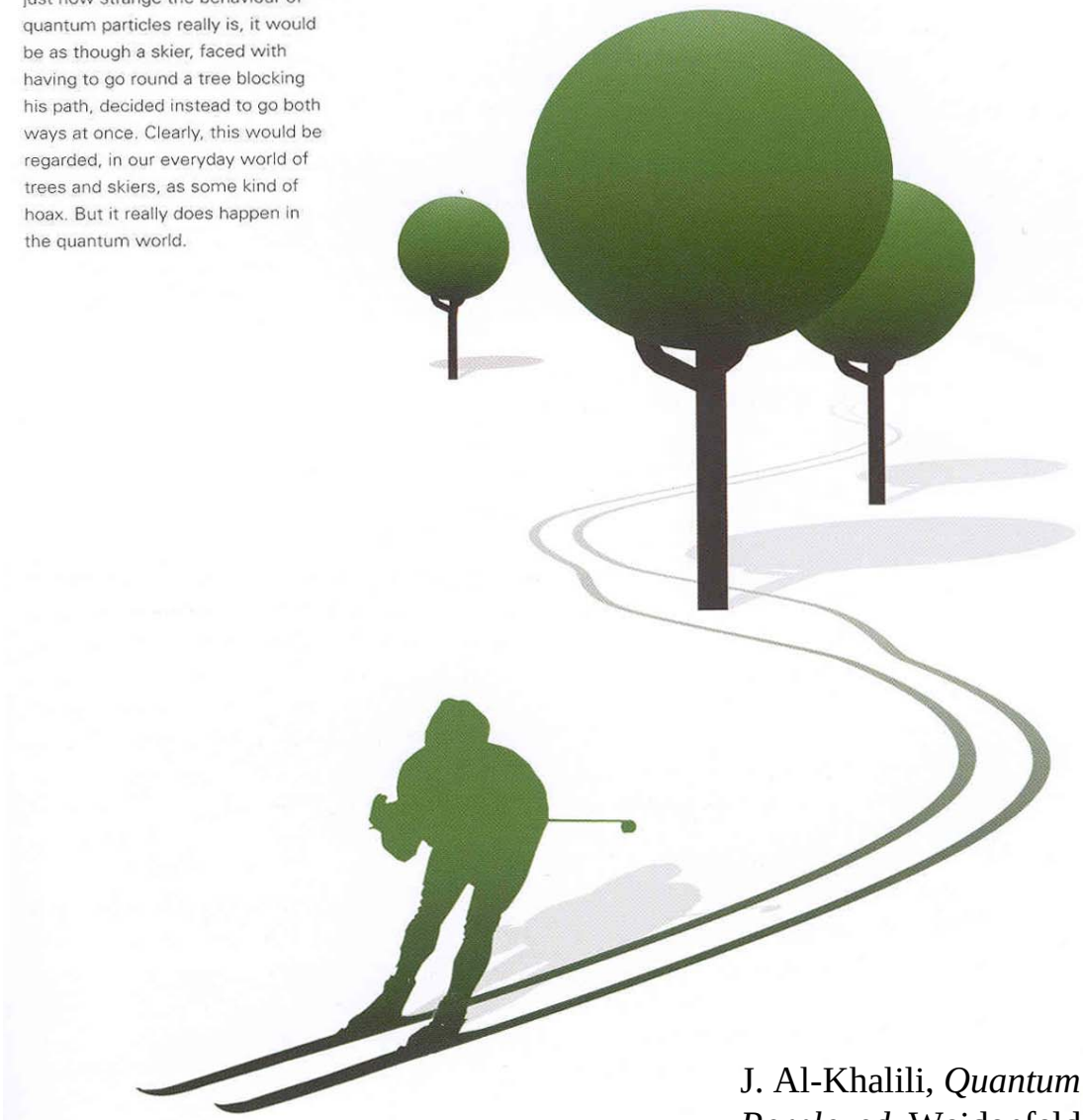


Fig. 5-33, p. 184

The quantum skier. To highlight just how strange the behaviour of quantum particles really is, it would be as though a skier, faced with having to go round a tree blocking his path, decided instead to go both ways at once. Clearly, this would be regarded, in our everyday world of trees and skiers, as some kind of hoax. But it really does happen in the quantum world.



J. Al-Khalili, *Quantum – A Guide for the Perplexed*, Weidenfeld & Nicolson, UK, 2003

Einstein vs. Bohr