Particle or wave?

Light:

Newton : particle

Huygens, Young, Fresnel, Fraunhofer : wave

Einstein : particle

Particle-wave duality: all forms of matter have both properties.

Bohr's principle of complementarity: it is NOT possible to simultaneously explain physical phenomena in terms of both particles and waves.

Wave mechanics

Wave function:

$$E(x,t) = A \cdot \sin(kx - \omega t)$$

A : amplitude

$\omega = \frac{2\pi}{T} = 2\pi f$: angular frequency

$k = \frac{2\pi}{\lambda}$: wave number (angular frequency in space)

Electrodynamics:

waves : $E, B \in \mathbb{R}$ $(\vec{E}, \vec{B} \in \mathbb{R}^3)$

intensity: $I \sim \vec{E}^2$ or $I \sim \vec{B}^2$

Quantum mechanics:

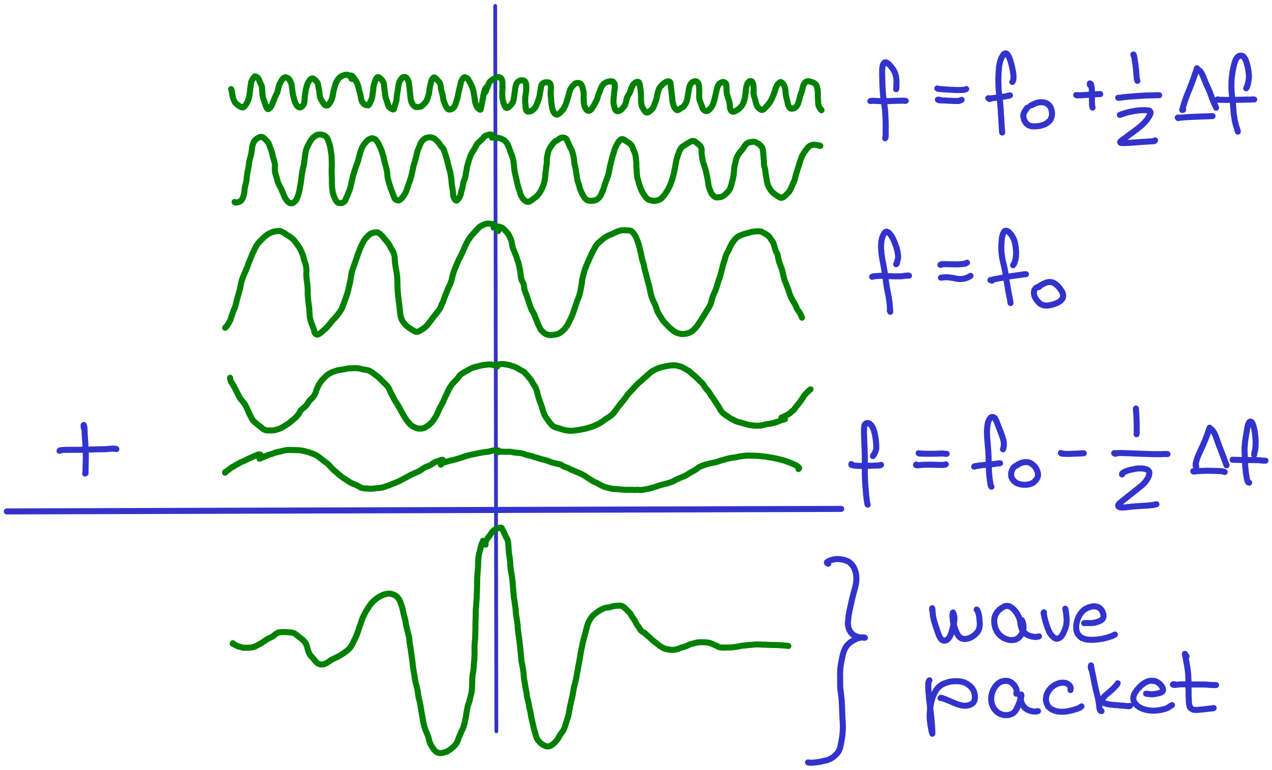
waves : $\Psi \in \mathbb{C}$

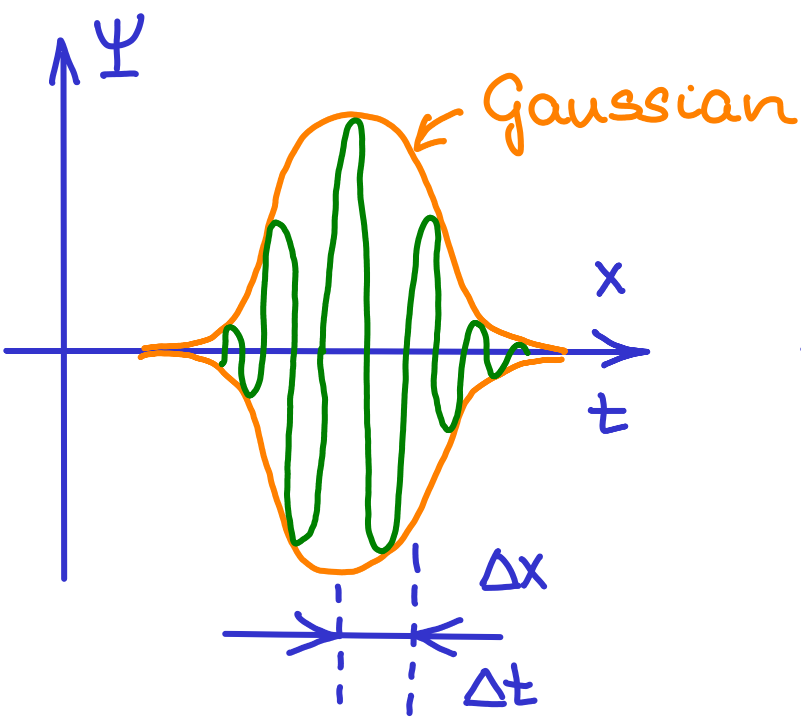
probability density:

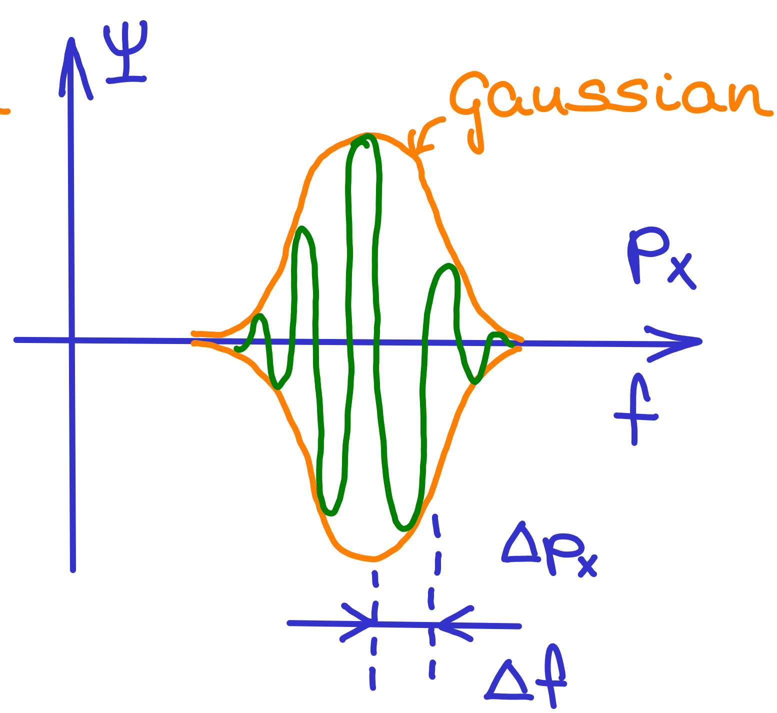
$$\rho \sim |\Psi|^2 = \Psi^* \cdot \Psi$$

Q : Particle or wave ?

A : Wave packet!

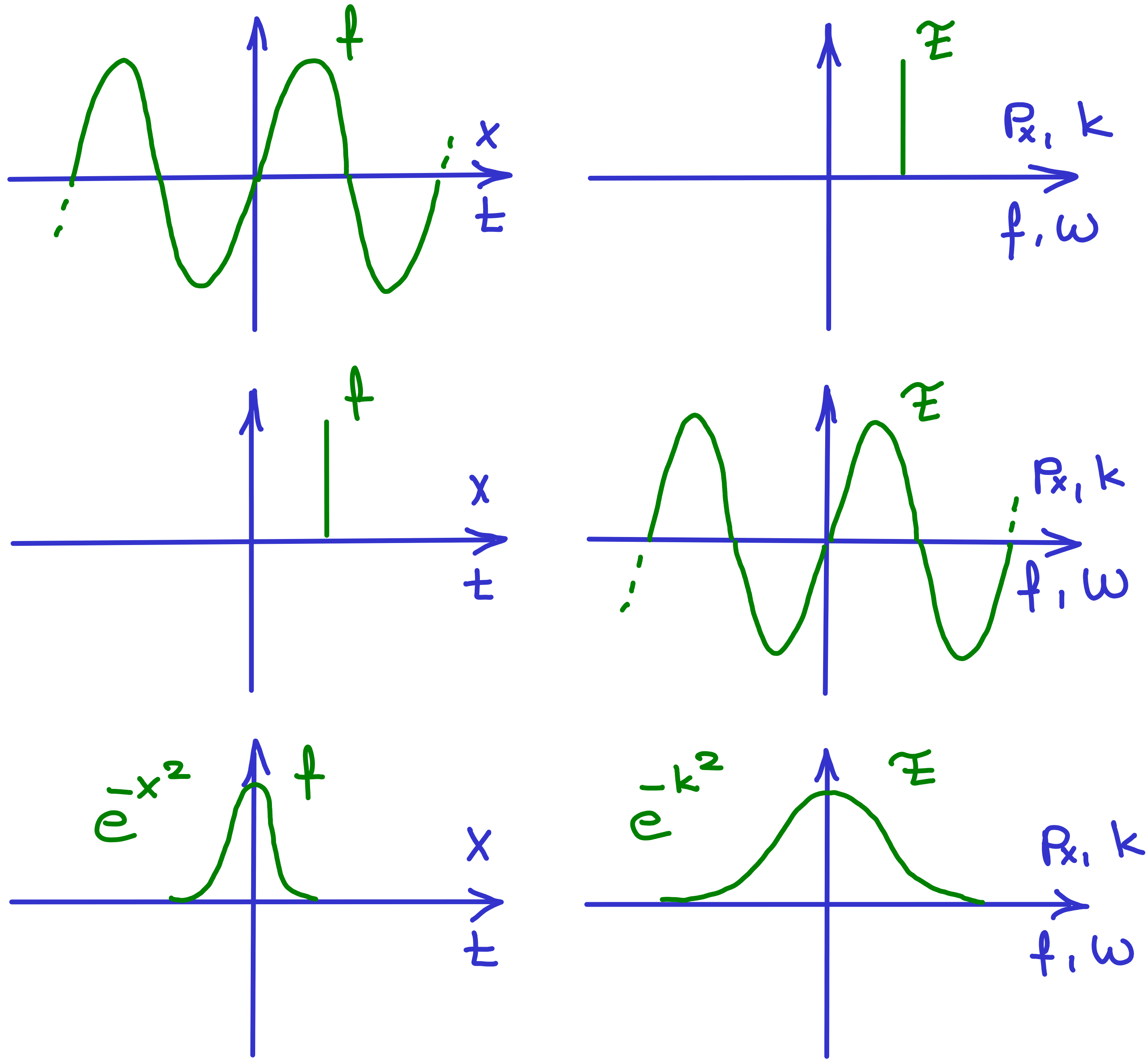






Fourier transformation

real space $\longleftrightarrow$ momentum space
time domain $\longleftrightarrow$ frequency domain



Heisenberg's Uncertainty Principle

Conjugate variables :

$$\begin{array}{ccccc} x & y & z & t & \varphi \\ \updownarrow & \updownarrow & \updownarrow & \updownarrow & \updownarrow \\ p_x & p_y & p_z & (-)E & L \end{array}$$

$$\boxed{\begin{aligned} \Delta x \cdot \Delta p_x &\geq \hbar/2 \\ \Delta y \cdot \Delta p_y &\geq \hbar/2 \\ \Delta z \cdot \Delta p_z &\geq \hbar/2 \\ \Delta t \cdot \Delta E &\geq \hbar/2 \\ \Delta \varphi \cdot \Delta L &\geq \hbar/2 \end{aligned}}$$

$$\hbar = \frac{h}{2\pi}$$

But :

$\Delta x \cdot \Delta y = 0$ $\quad$ $\Delta z \cdot \Delta p_x = 0$

$\Delta \varphi \cdot \Delta E = 0$ $\quad$ ...