

- The phase velocity of individual waves forming the matter wave that represents the particle is
$$v_p = \frac{\omega}{k} = \frac{E}{p} = \frac{\gamma mc^2}{\gamma mv} = \frac{c^2}{v}$$

Note that $v_p > c$

- The group velocity (the velocity of the matter wave representing the particle) is

$$v_g = \frac{d\omega}{dk} = \frac{dE}{dp} = v \quad \begin{array}{l} \uparrow \\ \text{particle velocity} \end{array}$$

\Rightarrow The velocity of the wavepacket (v_g) is the same as that of the particle, the packet can guide the motion of the particle.

- According to Heisenberg uncertainty principle

$$\Delta x \cdot \Delta p_x \geq \frac{\hbar}{2}$$

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