UNIT 1: WAVE-PARTICLE DUALITY

The Uncertainty Principle: Wave Picture

THE UNCERTAINTY PRINCIPLE: WAVE PICTURE

Consider a particle of known kinetic energy moving freely through space.

Wave function:

$$\psi(x,t) = A\sin(kx \pm \omega t)$$

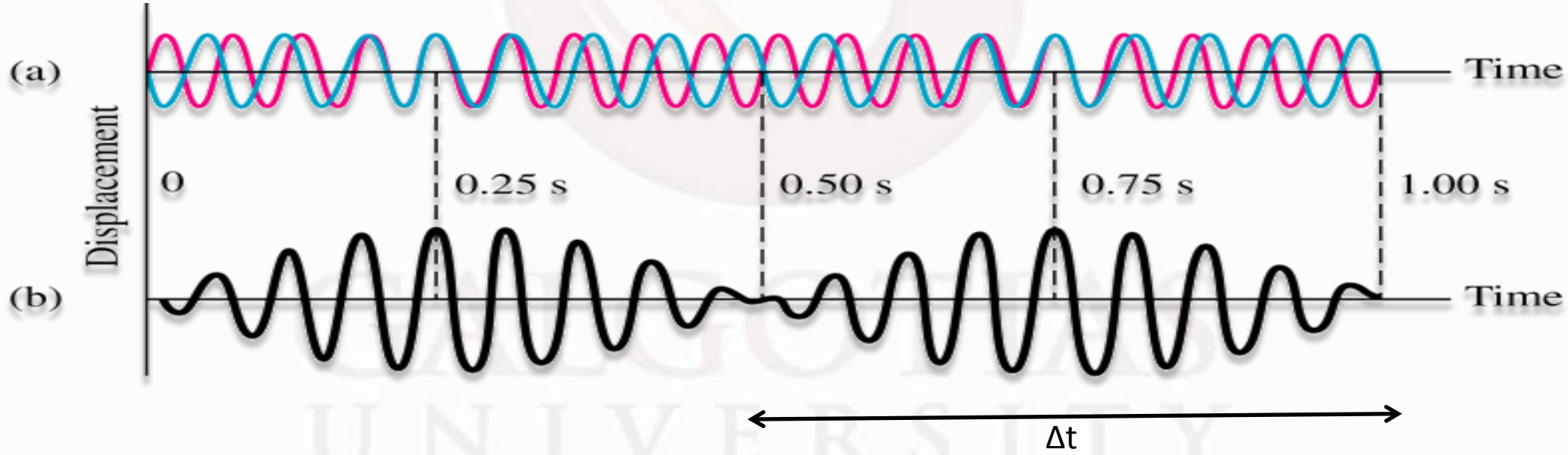
Momentum is exactly defined, but position of particle completely undefined.....

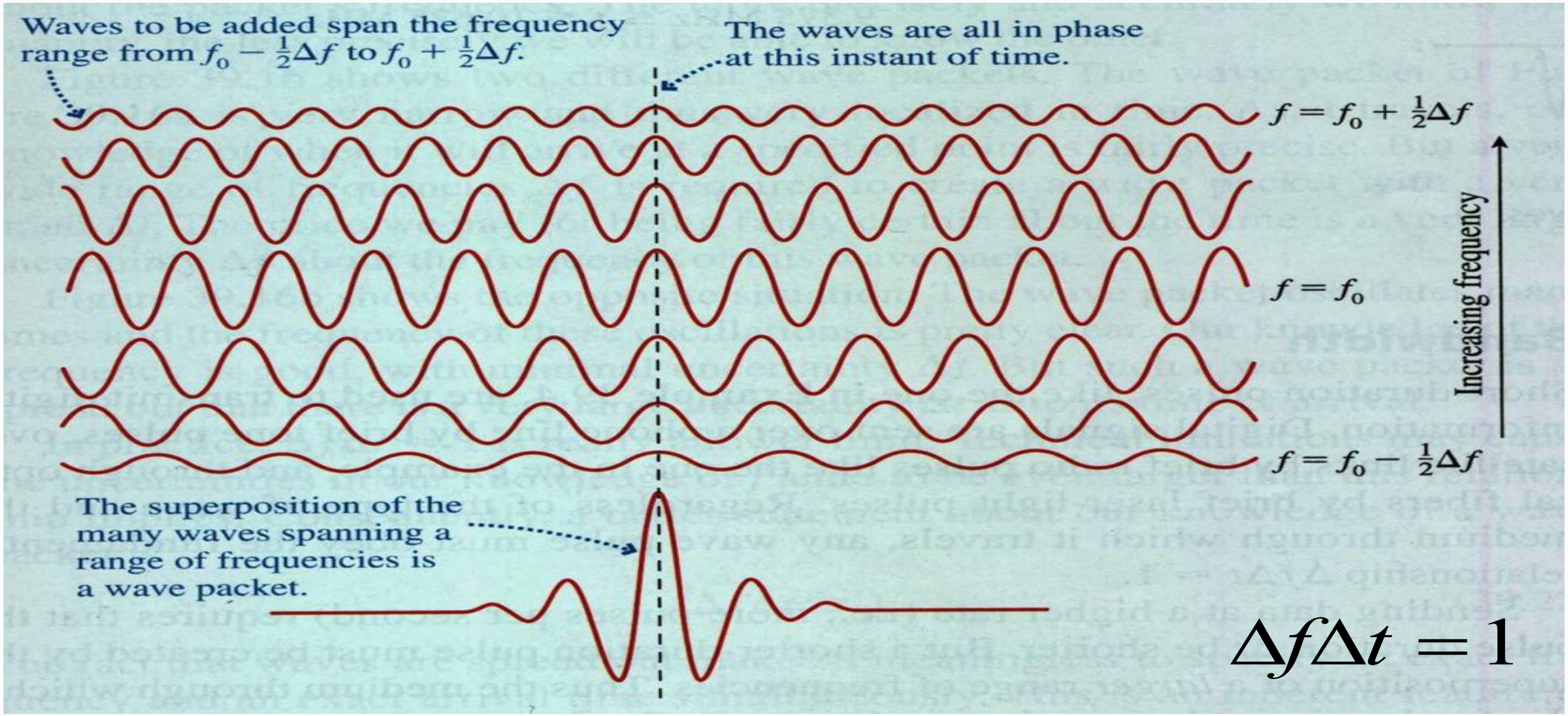
What happens if we combine waves of different wavelength?

BEATS (FROM SOUND WAVES)

These occur from the superposition of 2 waves of close, but different frequency:

$$f_{beat} = f_a - f_b = \Delta f$$




Waves to be added span the frequency range from $f_0 - \frac{1}{2}\Delta f$ to $f_0 + \frac{1}{2}\Delta f$.
The waves are all in phase at this instant of time.
$f = f_0 + \frac{1}{2}\Delta f$
$f = f_0$
$f = f_0 - \frac{1}{2}\Delta f$
Increasing frequency
The superposition of the many waves spanning a range of frequencies is a wave packet.
$\Delta f \Delta t = 1$
Δt

- So, by combining waves of different wavelength, we can produce localized "wave groups"

- The more different wavelengths we combine, the greater the degree of localization of the wave group (ie particle position becomes more well-defined)

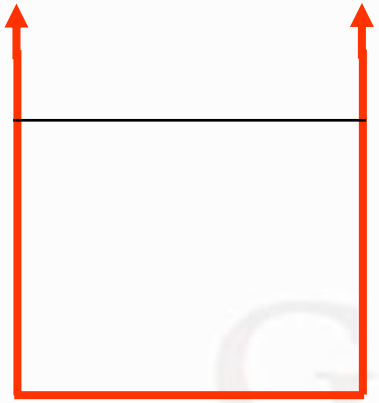
- We can obtain a totally localized wavefunction ($\Delta x = 0$) only by combining an infinite number of waves with different wavelength

- We thus lose all knowledge of the momentum of the particle...

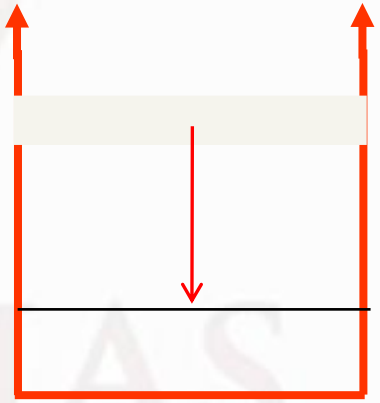
ENERGY-TIME UNCERTAINTY

- **Uncertainty principle also applies to simultaneous measurements of *energy* and *time***

$$\Delta E \Delta t \geq h$$



Stationary state
Zero energy spread



Decay to lower state with finite lifetime Δt: Energy broadening ΔE (explains, for example "natural linewidth" In atomic spectra)

REFERENCES

•CONCEPTS OF MODERN PHYSICS, ARTHUR BEISER, MCGRAW-HILL.
•INTRODUCTION TO MODERN PHYSICS, RICH MEYER, KENNARD, COOP, TATA MCGRAW HILL
•INTRODUCTION TO QUANTUM MECHANICS, DAVID J. GRIFFITH, PEARSON EDUCATION.