**General Waves (Review of Ch. 16)**

- **Wave:**
  - Propagation of a physical quantity in space over time
  \[ q = q(x, t) \]

- **Examples of waves:**
  - Water wave, wave on string, sound wave, earthquake wave, electromagnetic wave, “light”, quantum wave….

- Waves can be transverse or longitudinal.

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**Wave On A Stretched Rope**

- It is a transverse wave

- The wave speed is determined by the tension and the linear density of the rope:

\[

v = \sqrt{\frac{T}{\mu}} ; \quad \mu = \frac{\Delta m}{\Delta l}

\]

conceptual understanding only
Wave Function

Waves are described by wave functions in the form:

\[ y(x,t) = f(x-vt) \]

- \( y \): A certain physical quantity e.g. displacement in y direction
- \( f \): Can be any form
- \( x \): space position. Coefficient arranged to be 1
- \( t \): time. Its coefficient \( v \) is the wave speed
  - \( v > 0 \) moving right
  - \( v < 0 \) moving left

Practical Technique: Identify Wave Speed in A Wave Function

A wave function is in the form:

\[ y(x,t) = \frac{2}{(x-3.0t)^2 + 1} \]

- What is the wave speed:
  - Answer: 3.0 m/s to the right

Illustrate wave form at \( t = 0s,1s,2s \)

Example of waves: Tsunami

http://science.howstuffworks.com/nature/natural-disasters/tsunami2.htm

Sinusoidal Wave

- A wave describe a function \( y = \text{Asin}(kx - \omega t + \phi) \) is called sinusoidal wave. (Harmonic wave)
- wave speed \( v = \omega/k = \lambda f \)
- At each fixed position \( x \), the element is undergoing a harmonic oscillation.
  - The amplitude, frequency and phase constant of this oscillation are: \( |A|, \omega, -kx+\phi \)
- If we fix \( t \) and take a snap shot, the wave form is periodic over space \( (x) \). The spacing period \( \lambda \) is called wavelength and \( \lambda = 2\pi/k \) (see next page)
Parameters For A Sinusoidal Wave

- Snapshot with fixed $t$: wave length $\lambda = \frac{2\pi}{k}$
- Snapshot with fixed $x$: angular frequency $\omega$ = frequency $f = \frac{\omega}{2\pi}$
  - Period $T = \frac{1}{f}$
  - Amplitude $A$
- Wave Speed $v = \frac{\omega}{k}$
  - $v = \frac{f}{2}$, or
  - $v = \frac{1}{T}$
- Phase angle difference between two positions $\Delta \phi = -k\Delta x$

Sound waves: flute

- Speed of sound is 340 m/s. Length of a flute is ~ 0.6m. What is the lowest note flutes can make?

Sound waves: flute

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\[ f = \frac{c}{2L} = \frac{340 \text{ m/s}}{1.2 \text{ m}} = 280 \text{ Hz} \]

("B", one note below "middle C")

Listen.

Tacoma Narrows Bridge
**Linear Wave Equation**
- Linear wave equation
  - $c^2 = \frac{1}{y^2} \frac{\partial^2 y}{\partial t^2}$
  - Wave speed

- Sinusoidal wave
  - $y = A \sin(\frac{2\pi}{\lambda} x - 2\pi f t + \phi)$
  - $f$: frequency
  - $\phi$: Phase
  - $A$: Amplitude
  - $\lambda$: wavelength

General wave: superposition of sinusoidal waves

**Maxwell Equations (preview)**
- Gauss’s Law/ Coulomb’s Law
  - $\oint E \cdot dA = \frac{q}{\varepsilon_0}$
- Gauss’s Law of Magnetism, no magnetic charge
  - $\oint B \cdot dA = 0$
- Faraday’s Law
  - $\oint E \cdot dl = -\frac{d\Phi_B}{dt}$
- Ampere Maxwell Law
  - $\oint B \cdot dl = \mu_0 I + \varepsilon_0 \mu_0 \frac{d\Phi_E}{dt}$

Also, Lorentz force Law → $\mathbf{F} = q\mathbf{E} + q\mathbf{v} \times \mathbf{B}$

These are the foundations of the electromagnetism

**Electromagnetic Waves**
- EM wave equations (from last 2 of Maxwell’s eqns)
  - $\frac{\partial^2 E}{\partial x^2} - \mu_0 \varepsilon_0 \frac{\partial^2 B}{\partial t^2} = \frac{\partial^2 B}{\partial x^2} - \mu_0 \varepsilon_0 \frac{\partial^2 E}{\partial t^2}$

- Plane wave solutions:
  - $E = E_{max} \cos(kx - \omega t + \phi)$
  - $B = B_{max} \cos(kx - \omega t + \phi)$

- Speed of EM wave:
  \[ c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 2.9972 \times 10^8 \text{ m/s} \]
  In vacuum

- Wavelength and Frequency Relationship:
  \[ \lambda f = c = 3 \cdot 10^8 \text{ m/s} \]

- EM wave can be transmitted in vacuum!

**The EM Wave**
- Two polarizations possible (showing one)
Spectrum of EM Waves

- **VHF**: 30-300 MHz
- **UHF**: 300 MHz - 3.0 GHz
- **Cell phone**: 800/900/1800/1900 MHz
- **WiFi**: 2.4/5 GHz
- **Microwave Oven**: 2.4 GHz
- **Cordless phone**: 0.9/2.4/5.8 GHz

### Wavelength For TV Signals

- **Wavelength and frequency relationship for EM wave**
  \[ \lambda f = c = 3 \cdot 10^8 \text{ m/s} \text{ in vacuum} \]

- **Example**: Determine the wavelength (in air) of an EM wave of frequency 687 MHz (HDTV channel 3, CBS = UHF ch. 50)
  \[ \lambda = \frac{c}{f} = \frac{3 \cdot 10^8 \text{ m/s}}{687 \text{ MHz}} = \frac{3 \cdot 10^8 \text{ m/s}}{6.87 \cdot 10^6 \text{ s}^{-1}} = 0.44 \text{ m} \]

- **VHF**: 1-10 m, **UHF**: 0.1-1 m
- **Over-The-Air (OTA) DTV channels**: 90% of them in UHF band \( \lambda \sim 0.4 \text{ - } 0.6 \text{ m} \)

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**Now you see it, now you don’t:**
- **x-ray vs visible light**
- **X-ray vs visible**

- **unknown**, 2011
- **Bertha Roentgen**, 1895
- **me**, 2005

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**Neutrinos from SN-1987A**

- **SN1987A** confirmed our understanding of:
  - Luminosity
  - Energies of neutrinos
  - Duration of burst
- are qualitatively correct.
Now you see it, now you don’t: x-ray vs visible light

Now you see it, now you don’t: Infrared vs visible light

Evidence of Dark Matter

Merger of Galactic Clusters

Infrared (IR), false color added
visible

Strings on a Bass

http://vimeo.com/4041788