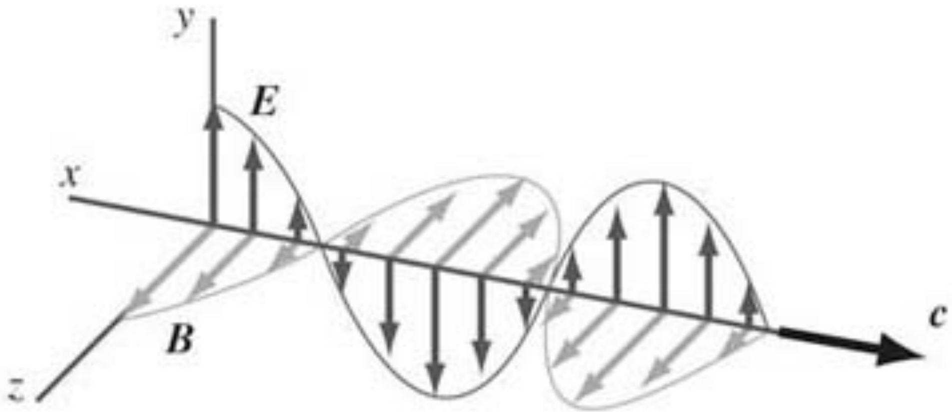
## Module 13

# Light

## Session Slides with Notes

# Properties of Light

# Electromagnetic Wave Propagation



- transverse waves

$c = 3.0 \times 10^8$ m/s

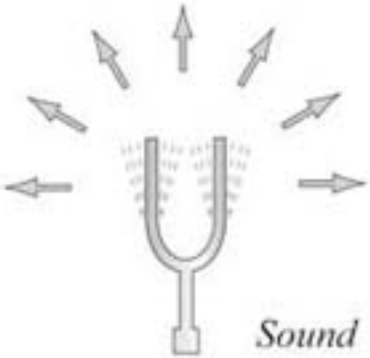
Which of the following distinguishes electromagnetic waves from sound waves?

a. Electromagnetic waves are longitudinal. Sound waves are transverse.

[✓ b.] Electromagnetic waves do not require a medium.

c. Electromagnetic waves carry energy.

d. Electromagnetic waves can’t be polarized.



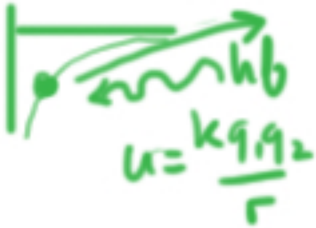
!

$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

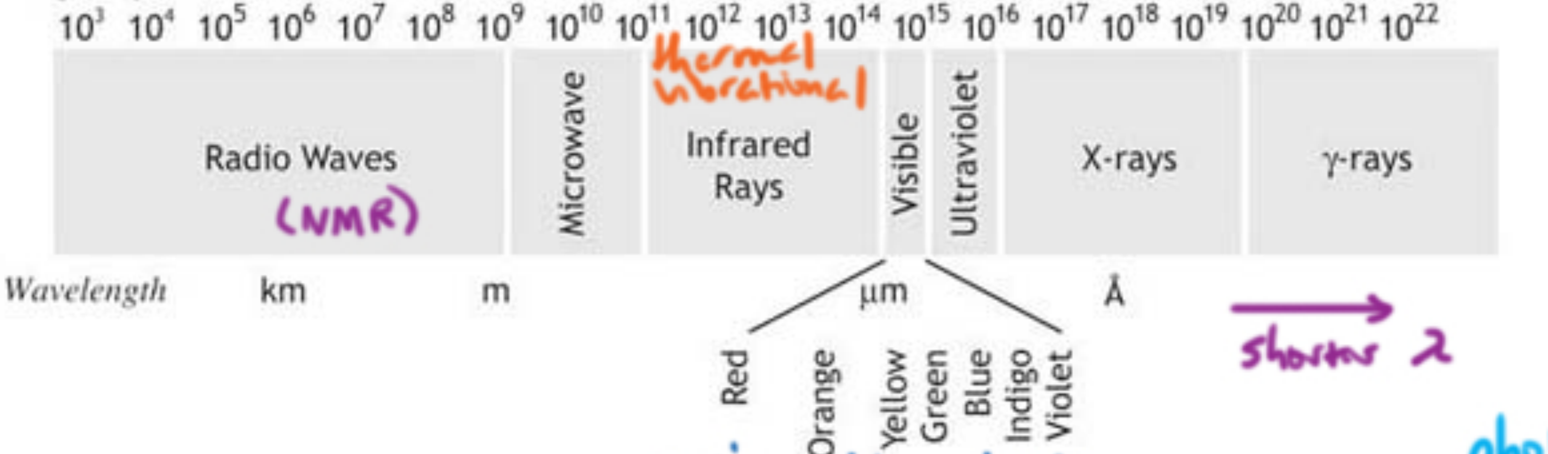
# The Electromagnetic Spectrum

$E = hf$

electronic transition → ionizing radiation



$u = \frac{kq_1q_2}{r}$



→ shorter λ

- pigments
- crystal field splitting

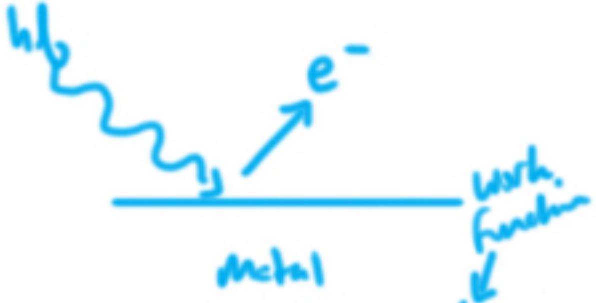
UV absorbance

visible

fluorescence

- phosphorescence
- chemiluminescence

photoelectric effect



$KE = hf - \phi$

$$c = f\lambda$$

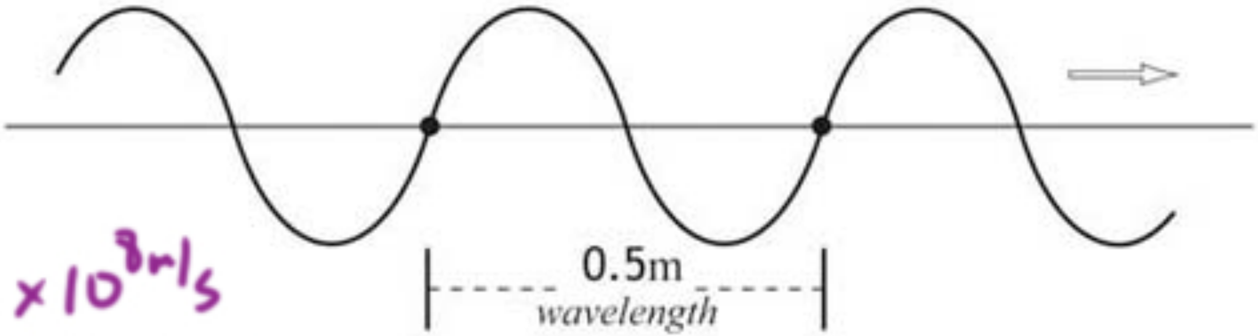
$$= 3 \times 10^8 \; \frac{m}{s}$$

$c$ = speed of light
$f$ = frequency
$\lambda$ = wavelength

A radio wave travelling through space has a wavelength of 0.5m. What is the frequency of the wave?

$v = f\lambda$

$c = f\lambda$



$$f = \frac{3 \times 10^8 \, m/s}{0.5m}$$

Divide either f or $\lambda$ into wave sped to get the other.

$$\frac{3 \times 10^8}{5 \times 10^{-1}}$$

$= 0.6 \times 10^9$

$= 6 \times 10^8$

a. 150 MHz

b. 250 MHz

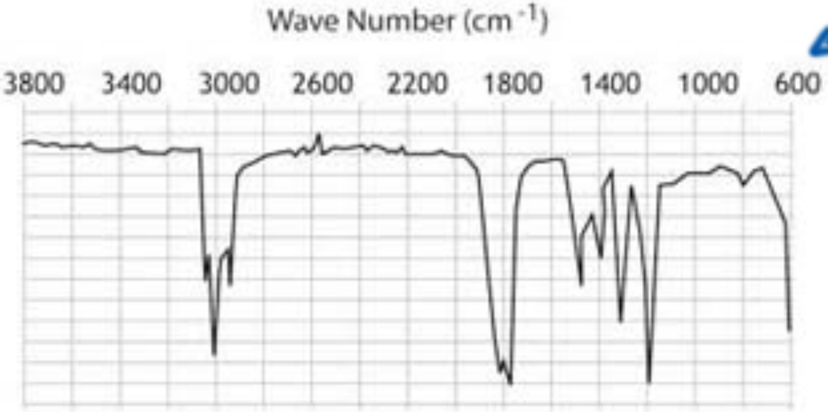
c. 300 MHz

[✓ d.] 600 MHz

$MHz = 10^6 \, Hz$

Infrared spectroscopy is a technique to identify an unknown compound by assaying the absorption of frequencies of infrared radiation matching the vibrational frequencies associated with the chemical bonds within the substance.

Infrared spectrographs usually represent absorption frequencies as *wave numbers* ($\mathrm{cm}^{-1}$). Wave numbers are reciprocal values of the wavelengths of absorbed radiation.



The unknown substance depicted by the spectrograph above has a strong absorbance at 3000 $\mathrm{cm}^{-1}$. What is the frequency in Hz of this peak?

$(3000\,\mathrm{cm}^{-1})(3.0 \times 10^{10}\,\mathrm{cm/s})$

a. $1 \times 10^{-5}$ Hz  b. $1 \times 10^{7}$ Hz  c. $9 \times 10^{11}$ Hz  [✓ d.] $9 \times 10^{13}$ Hz

assume

$v = c$

wave numbers

$k = \frac{1}{\lambda}$

$\lambda = \frac{\text{meters}}{\text{cycle}}$

$k = \frac{\text{cycles}}{\text{meter}}$

or $\frac{\text{cycles}}{\text{cm}}$

or $\mathrm{cm}^{-1}$

$v = \lambda f \quad f = \frac{v}{\lambda}$

$f = kv$

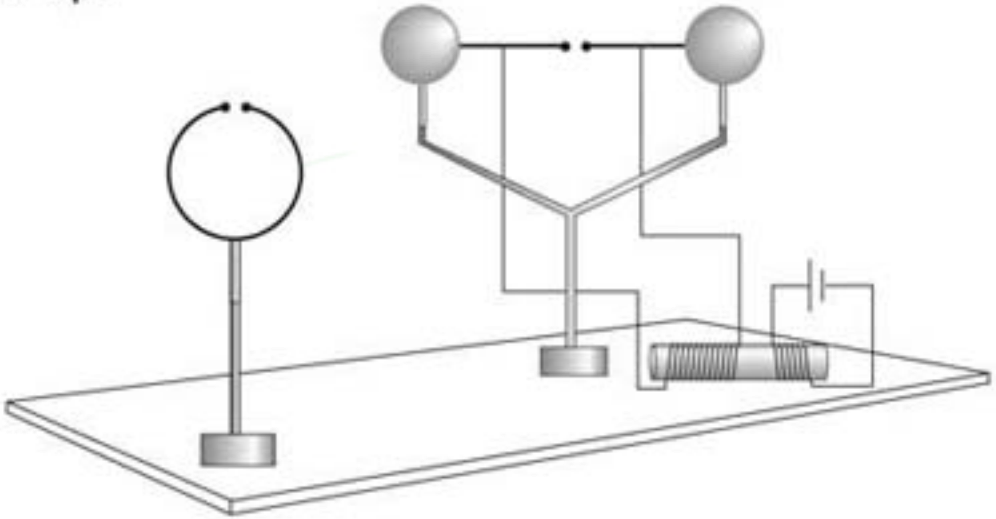
When sufficient voltage is supplied to the induction coil in the apparatus below, an oscillatory discharge occurs across the spark gap between the two electrode spheres. The oscillatory discharge occurs at the resonance frequency of the induction coil/electrode combination, an LC circuit, at approximately 1 X $10^8$ Hz. When the resonance frequency of a nearby conducting loop with its own spark gap is adjusted to match this frequency, sparks are observed across the gap in the nearby loop, even though the loop is not touching the induction coil/electrode apparatus. What are being transmitted by the coil/electrode apparatus to the loop to cause sparking in the loop?

a. cathode rays

[✓ b.] radio waves

c. alpha particles

d. x-rays



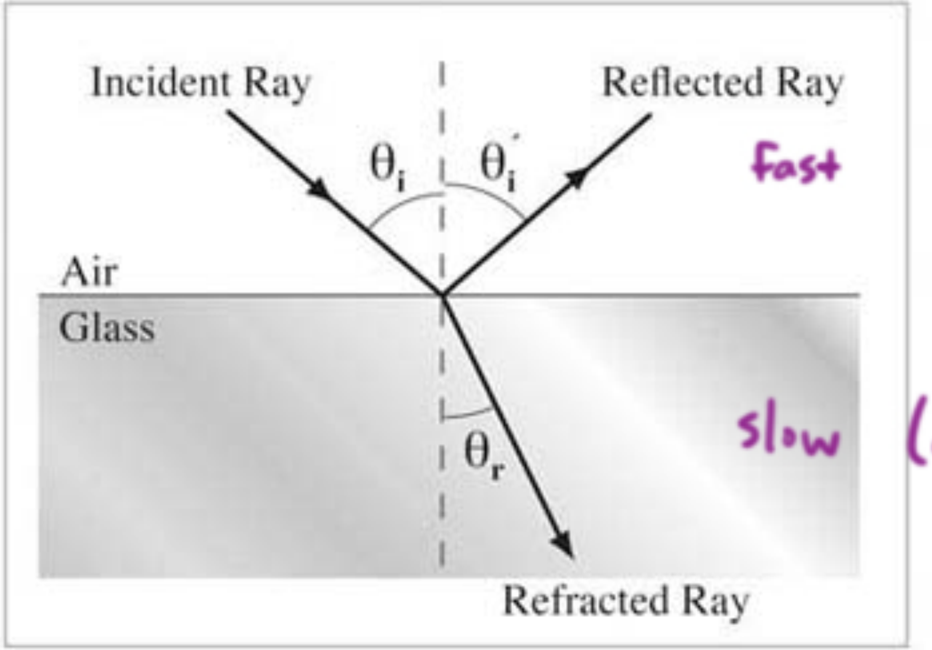
# Reflection and Refraction

$n = \frac{c}{v}$

*Law of Reflection*

$$\theta_i = \theta_i'$$

$\theta_i$ = angle of incidence
$\theta_i'$ = angle of reflection



(n ~ 1.5)

*Snell's Law Governing Refraction*

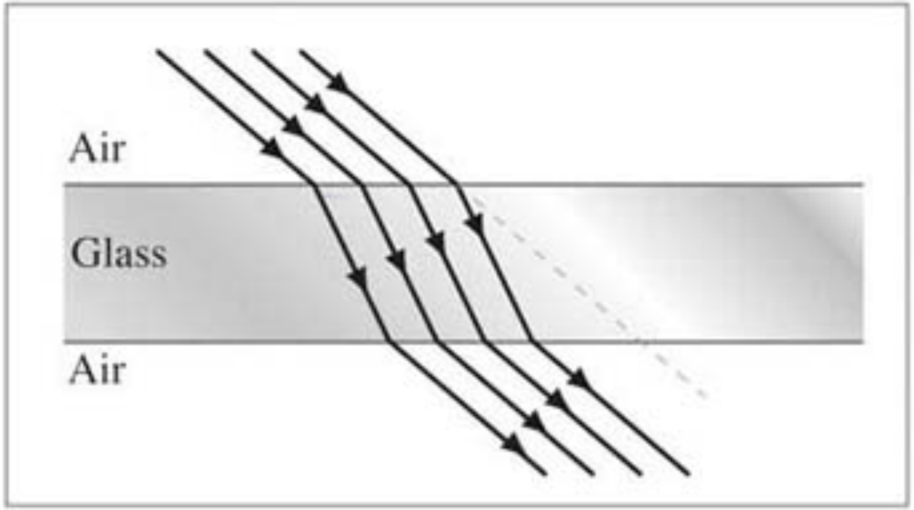
$$n_1 \sin \theta_i = n_2 \sin \theta_r$$

$n_1$ = index of refraction in first medium
$\theta_i$ = angle of incidence
$n_2$ = index of refraction in second medium
$\theta_r$ = angle of refraction

# Index of Refraction

$$n = \frac{c}{v}$$

$n$ = index of refraction of medium
$c$ = speed of light in a vacuum
$v$ = speed of light in the medium



$$\frac{v_2}{v_1} = \frac{n_1}{n_2} \qquad \frac{\lambda_2}{\lambda_1} = \frac{v_2}{v_1} \qquad \frac{\lambda_2}{\lambda_1} = \frac{n_1}{n_2}$$

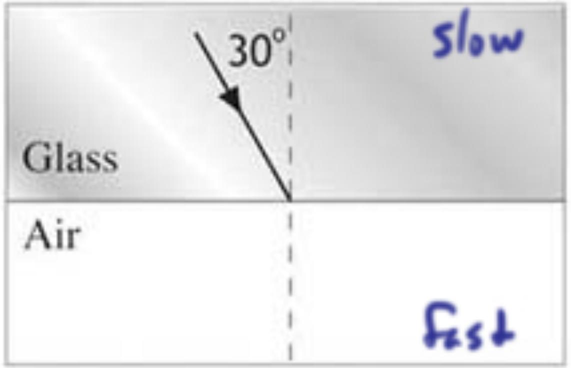
entering the new medium
- $v$ is changed
- $f$ doesn't change
- $v = f\lambda$

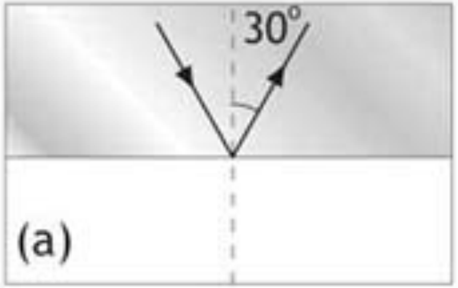
$\lambda$ must change

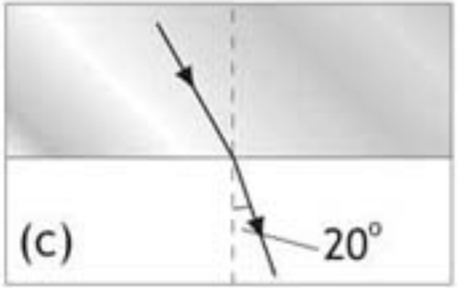
entering a slow medium
$\lambda$ shortens

$$n_2\lambda_2 = n_1\lambda_1$$

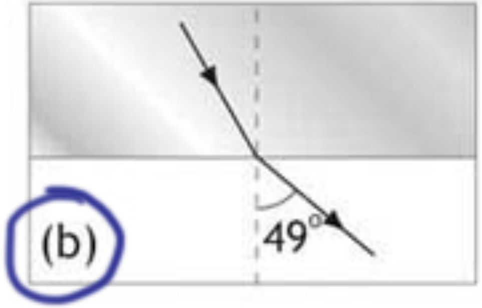
A light ray travelling through glass ($n$ = 1.5) is incident on the smooth, flat interface between the glass and outside air ($n$ = 1.0). The light is travelling at an angle of 30° to the normal as pictured at right. Which results from refraction at the boundary?

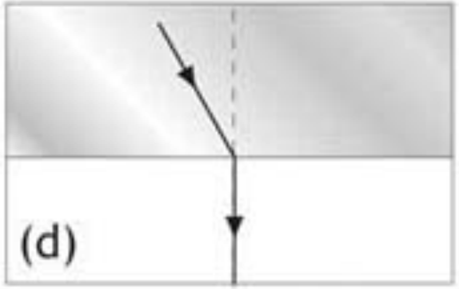




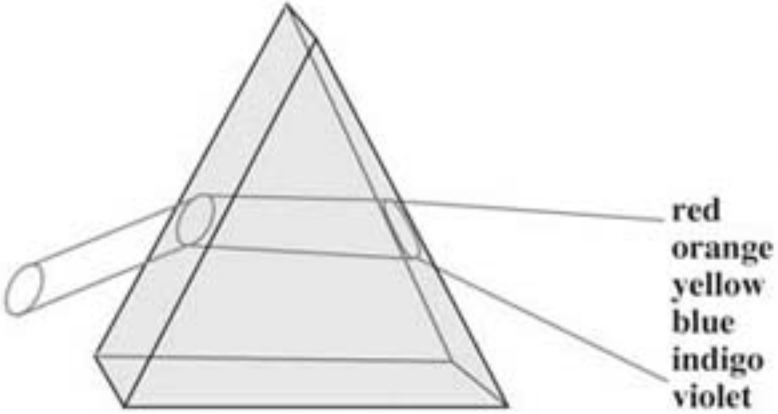


$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$





A prism disperses white light into its spectrum, revealing the colored components of white light. Which of the following accounts for this behavior?



Dispersion

because of slightly different index of refraction for different frequencies.

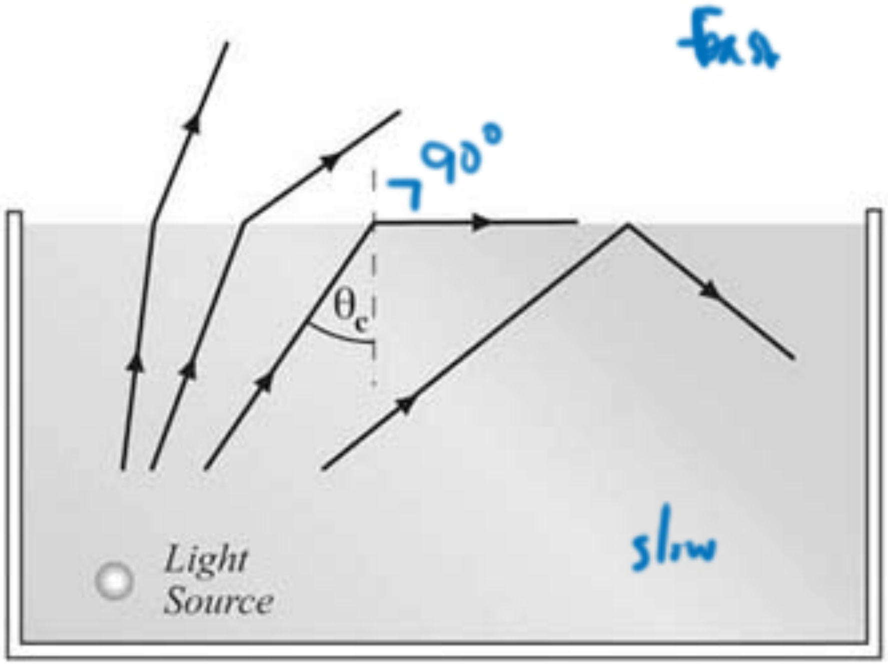
a. Red rays are refracted the most by the prism, violet rays the least.

b. The product of wavelength and frequency is the same for all colors in the glass but not in empty space.

[✓ c.] Visible light of longer wavelength moves with greater speed in glass than visible light of shorter wavelength.

d. Moving from a slower to a faster media increases the wavelength of a particular light ray.

# The Critical Angle and Internal Reflection



$\sin\theta_c n_1 = \sin(90^\circ) n_2$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$(n_1 > n_2)$$

$\theta_c$ = critical angle

$n_1$ = index of refraction in first medium

$n_2$ = index of refraction in second medium

diamond

$\sin\theta_c = \frac{1}{2.5}$

$\theta_c < 30^\circ$

diamond $n_1 = 2.5$

A typical fiber optic cable consists of two concentric layers: the outer cladding and the inner core. The index of refraction of the core is higher than that of the cladding. With a straight or slightly bending fiber, the signal always strikes the core-cladding interface at an angle (from the normal) higher than the critical angle. Therefore, the light is reflected back into the fiber which allows transmission over great distance.

$$n = \frac{c}{v}$$

$$v = \frac{c}{n}$$

$$v = \frac{3.0 \times 10^8 \, m/s}{1.5}$$

$$= 2 \times 10^8 \, m/s$$

What is the minimum time required for the cable above to transmit a signal over a distance of 90 km?

$$\Delta x = 90 \, km$$

$$\Delta t = \frac{9 \times 10^4 \, m}{2 \times 10^8 \, m/s} = 4.5 \times 10^{-4} \, s$$

$$\Delta x = 9 \times 10^4 \, m$$

a. $3.0 \times 10^{-7}$ s

c. $3.0 \times 10^{-4}$ s

b. $2.0 \times 10^{-4}$ s

[✓ d.] $4.5 \times 10^{-4}$ s

$$\frac{\Delta x}{\Delta t} = v \qquad \Delta t = \frac{\Delta x}{v}$$