

1.1 Fluid pressure:

-Pressure is a very interesting concept. It results from gravity, and it is like force, but it acts in all directions at the same time. It is defined as force per unit area, so its units are N/m², which are also called pascals (Pa).

$$P = \frac{F}{A} = \frac{mg}{A} = \frac{\rho Vg}{A} = \frac{\rho Ahg}{A} = \rho hg$$

-A = area of the fluid's base

-h = height (aka d = depth)

-ρ = density of fluid (water, air, etc. has different density) (Also, p = mass density (kg/m³) * area (m²))

Gauge Pressure VS Absolute Pressure

-Gauge: For a lot of applications, we only care how much more pressure something has than atmospheric pressure. This difference from atmospheric pressure is called gauge pressure (because it is what a lot of pressure gauges show).

$$P = \rho hg$$

-Absolute: You can always figure out the absolute pressure something has if you know its gauge pressure by adding atmospheric pressure to it.

$$P = P_{atm} + phg$$

Mazur 18.1 Forces in a Fluid:

-Can't describe a fluid's velocity, since it can differ at different parts.

-We can describe the velocity at a single point though.

When a gas is subjected to bulk stress, its mass den-

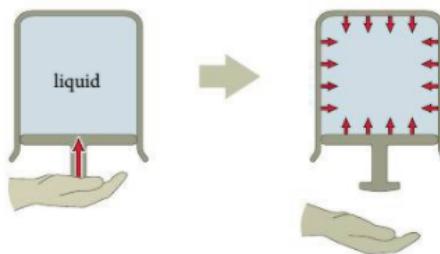
sity and volume change easily. When a liquid is sub-

jected to bulk stress, its mass density and volume can

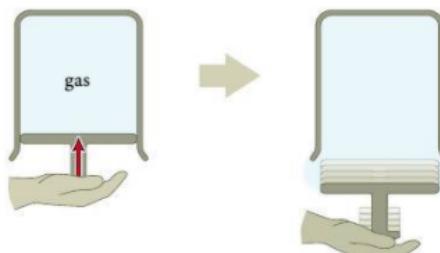
be considered unchanged.

Figure 18.5 Liquids can sustain negative pressures, whereas pressures in a gas can be positive only.

(a) Because liquid particles exert attractive forces on each other and on the container walls, liquid can hold piston up against force of gravity



(b) Gases expand to fill any volume and therefore cannot sustain negative pressures



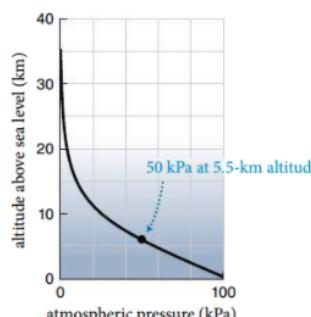
-Pushing out on a surface is Positive Pressure, pushing inward on a surface is Negative Pressure.

The pressure in a liquid at rest in a container decreases linearly with height, regardless of the shape of the container



-Gas does not decrease linearly and is less pronounced

Figure 18.39 Variation in atmospheric pressure with altitude above sea level.



-Pascal's Principle

A pressure change applied to an enclosed liquid is transmitted undiminished to every part of the liquid and to the walls of the container in contact with the liquid.

Mazur 18.5 Pressure and Gravity:

-The air pressure at sea level, aka 1 atm.

$$P_{\text{atm}} = 101.3 \text{ kPa}$$

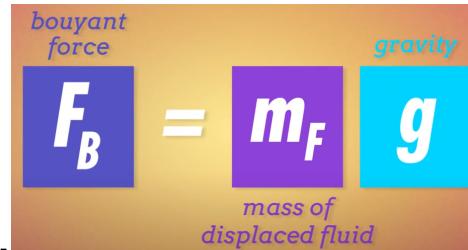
-If the pressure is less than 1 Pa, it's good enough to round it to 0 and is considered a vacuum.

-Suction cup tip dart stuck to the ceiling example to show difference in pressure.

18.14 As the suction cup hits the ceiling, the bowl of the cup collapses, forcing out the air that was initially in the bowl. Consequently, the pressure

in the space between the cup and the ceiling is lower than atmospheric pressure. As long as the seal between the cup edge and the ceiling is maintained, the air in the room underneath the cup exerts an upward force greater than the downward force exerted by the air inside the cup that holds the dart up against the ceiling.

2.2 Buoyant force



$$F_b = -\rho g V$$

F_b = buoyant force

ρ = fluid density

g = acceleration due to gravity

V = fluid volume

-If this is greater than gravity (m^*g), then it'll float.

-aka if the displaced water weight is equal to (neutral, no accel) or greater than the object's weight, the object floats.

-Objects with different densities and the same dimension feel the same buoyancy force. Gravity's effect is stronger depending on the density, more stuff in the volume means stronger pull causing objects with density that's higher than the liquid's density to sink. (Water's density is 997 or ~1000 kg/m³)

To compare, you need

-For both the Object and the Liquid Displaced

-Volume ($L = 0.001 \text{ m}^3$)

-Mass (kg)

-Force of Gravity aka Weight mg (N)

-If the weight of the water displaced is equal or higher than the weight, the object floats.

-(There's also density, which you can then figure out mass and volume from)

Mazur 18.3 Fluid Flow

-Laminar VS Turbulent

-Laminar: velocity of the fluid at any location is constant.

-Turbulent: velocity changes with time, very chaotic.

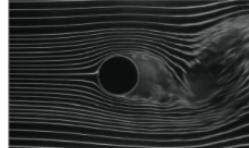
-Streamlines

-Lines representing the path of the fluid.



Wow downforce

-In turbulent flow, the lines become noisy and form vortices.



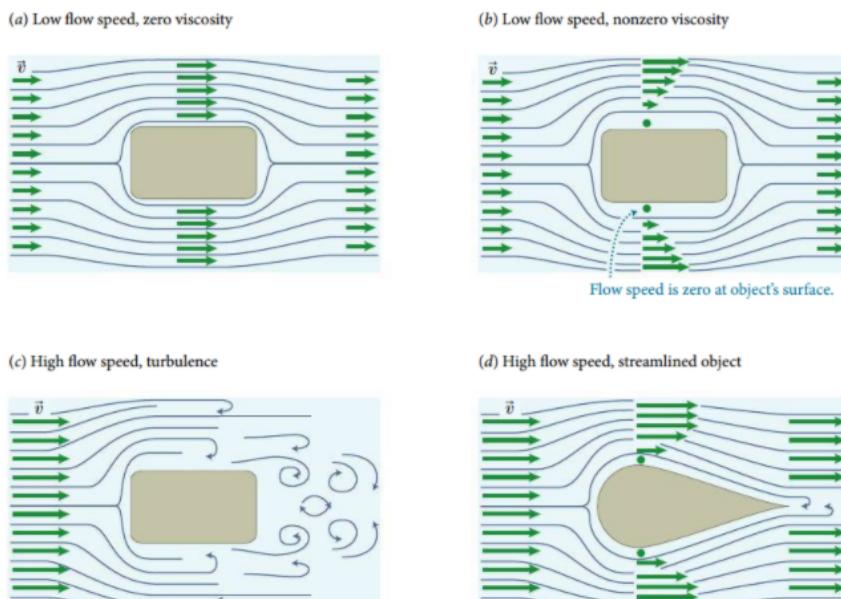
Don't slipstream behind that

-Viscosity

-The fluid's resistance to shear stress

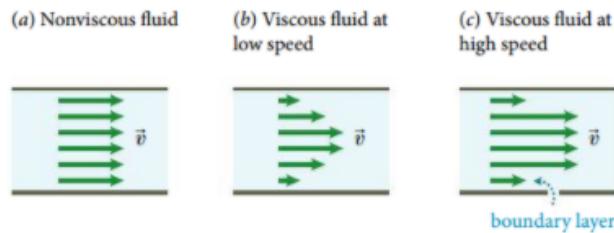
-Factors determining turbulent or laminar flow past an object are the liquid's flow speed & viscosity, and the shape of the object

Figure 18.18 Whether the flow of fluid past a stationary object is laminar or turbulent depends on the fluid's speed and viscosity and on the object's shape.



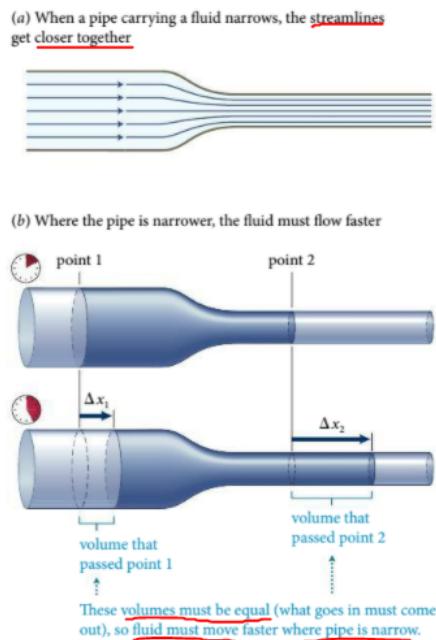
-Fluid with different viscosity through pipe

Figure 18.19 Flow speed patterns through a pipe of fixed diameter.



-Fluid through pipe with different size

Figure 18.20 What happens when a fluid flows from a wider region of a pipe into a narrower region.



A flowing fluid speeds up when the region through which it flows narrows and slows down when the region through which it flows widens. The density of streamlines reflects the changes in flow speed: When streamlines in a laminar flow get closer together, the flow speed increases; when they get farther apart, the flow speed decreases.

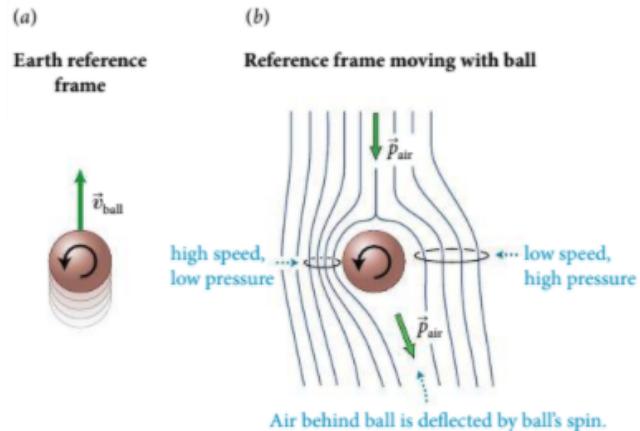
-The surrounding fluid is exerting a force "to the right" on the particle while in the tapered region of the pipe.

-Bernoulli Effect / Principle

When the flow speed in a laminar flow increases, the pressure in the fluid decreases.

-Spinning ball pulls on air to veer left (top down view)

Figure 18.21 Motion of a spinning ball as seen (a) from the Earth reference frame and (b) from a reference frame moving along with the ball. Because the air is dragged along with the ball surface, the air moves faster to the left of the ball and more slowly to the right of the ball.



Mazur 18.7 Bernoulli's Equations

-Only for laminar flow

-Shear forces due to viscosity are negligible (aka non-viscous)

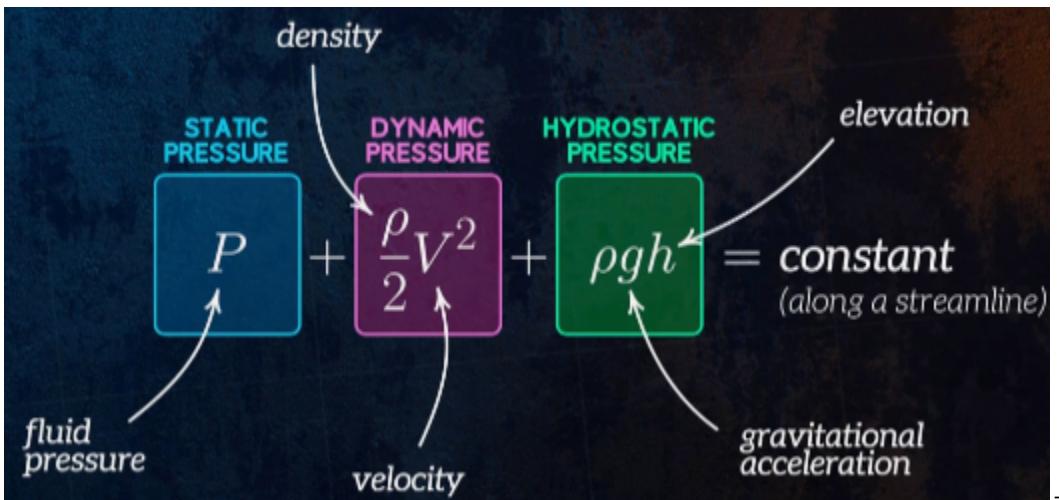
-Fluid is incompressible (like most liquids)

$$P_1 + \rho gy_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho gy_2 + \frac{1}{2}\rho v_2^2$$

(laminar flow
of incompressible,
nonviscous fluid).

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

(horizontal laminar flow
of incompressible,
nonviscous fluid).



-Static Pressure = Pressure Energy

-Dynamic Pressure = Kinetic Energy

-Hydrostatic Pressure = Potential Energy

-All 3 must be conserved

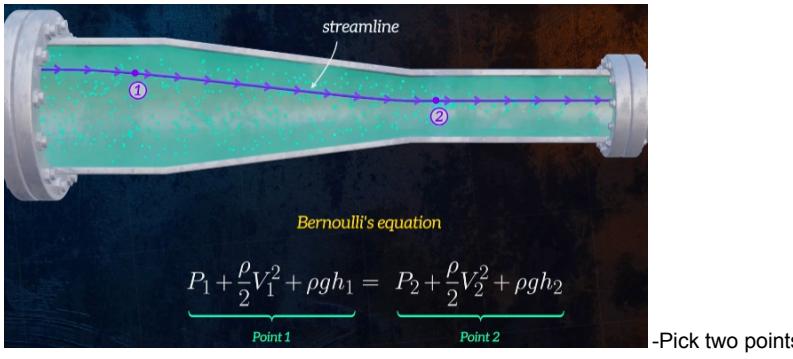
HEAD FORM

$$\frac{P}{\rho g} + \frac{V^2}{2g} + h = \text{constant} \quad (\text{along a streamline})$$

ENERGY FORM

$$\frac{P}{\rho} + \frac{V^2}{2} + gh = \text{constant} \quad (\text{along a streamline})$$

-Example of usage

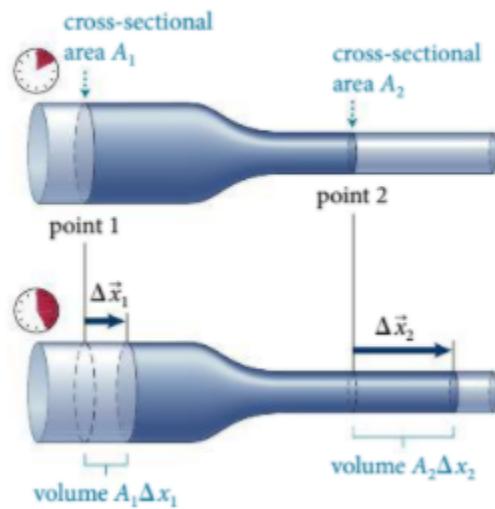


-Bernoulli's Principle as an equation (Continuity)

$$\rho_1 A_1 |\Delta x_1| = \rho_2 A_2 |\Delta x_2| \quad (\text{laminar flow of nonviscous fluid}).$$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \quad (\text{laminar flow of nonviscous fluid}).$$

Figure 18.52 A fluid flows through a tapered tube.



-Fresh water density:

-1000 kg/m^3

3.2 Review of circular motion

-Standard harmonic wave mapped to time (

$$f(t) = A \sin(B(t+C)) + D$$

-Period (s)

$$T = \frac{d}{v} = \frac{2\pi r}{v} \quad (\text{d=diameter, r=radius, v=velocity})$$

• period is $2\pi/B$

-Frequency (cycles per second = Hz)

$$f = \frac{1}{T}$$

-Angular Velocity/Frequency (rad/s = Hz)

$$\omega = 2\pi f = \frac{2\pi}{T} = 2\pi \cdot \frac{v}{2\pi r} = \frac{v}{r}$$

-Elastic Potential Energy (J)

$$\Delta U_s = \frac{1}{2}k(x - x_0)^2$$

-Forces from springs

-Hooke's Law

$$F = -k(x - x_0) \quad \text{where } x_0 \text{ is the equilibrium length of the spring}$$

-Made into DE

$$F = ma = -kx$$

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x$$

$$x(t) = A \sin(\omega t + \phi)$$

$$\omega^2 = \frac{k}{m}$$

(k=spring constant N/m, m=mass kg)

- $\omega = \sqrt{\frac{k}{m}}$
- $f = \frac{1}{2\pi}\omega = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$
- $T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}}$ $A = v_0/\omega$

-Total Energy (Hooke's & Kinetic)

$$E = U + K = \frac{1}{2}kx^2 + \frac{1}{2}mv^2$$

$$E = U(x = A) = 1/2kA^2 \rightarrow \frac{1}{2}kx^2 + \frac{1}{2}mv^2 = \frac{1}{2}kA^2$$

-Pendulum Period (Rough estimate, good for angle of release that's less than 15°)

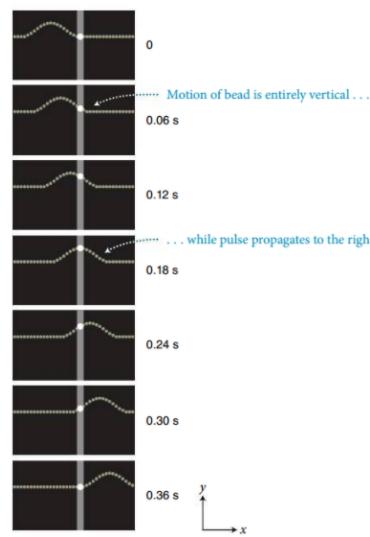
$$T = 2\pi\sqrt{\frac{l}{g}}$$

(mass is not factor!) (The release/max angle is the amplitude.)

Mazur 16.1 Representing wave graphically

-The wave pulse makes the bead/particle here move only up and down which returns them to their original position.

Figure 16.3 Video frames sequence of a wave pulse propagating along a string of beads.



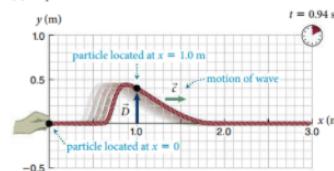
The motion of a wave (or of a single wave pulse) is distinct from the motion of the particles in the medium that transmits the wave (or pulse).

The wave speed c of a wave pulse along a string is constant.

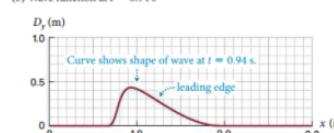
-That means the wave speed ($c = \text{pulse displacement } (\Delta x) / \text{time taken } (\Delta t)$, SI: m/s) is independent from the velocity of the medium's particles (v).

Figure 16.4 Distinction between the wave function and displacement curves for a triangular wave pulse propagating along a string parallel to the x axis.

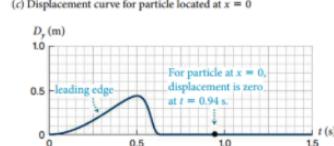
(a) Snapshot of wave at $t = 0.94$ s



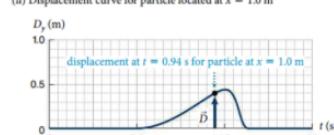
(b) Wave function at $t = 0.94$ s



(c) Displacement curve for particle located at $x = 0$



(d) Displacement curve for particle located at $x = 1.0$ m



-Displacement of a point in medium is opposite direction as wave appearance

-Transverse Wave: the medium movement is perpendicular to the wave movement.

-Longitude Wave: the medium movement is parallel to the wave movement.

-Spring example

Figure 16.5 Longitudinal wave pulse propagating along a spring.

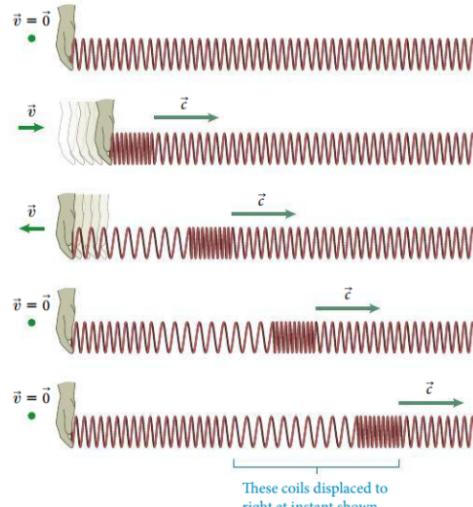
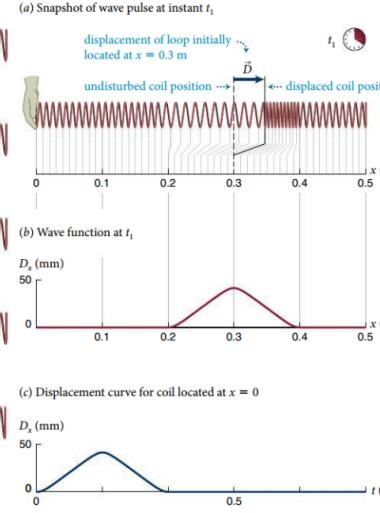
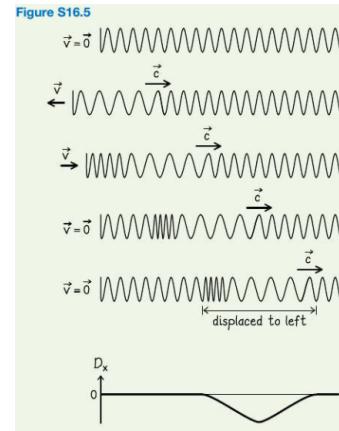


Figure 16.6 Wave function and displacement curve for a longitudinal wave pulse propagating along a spring.



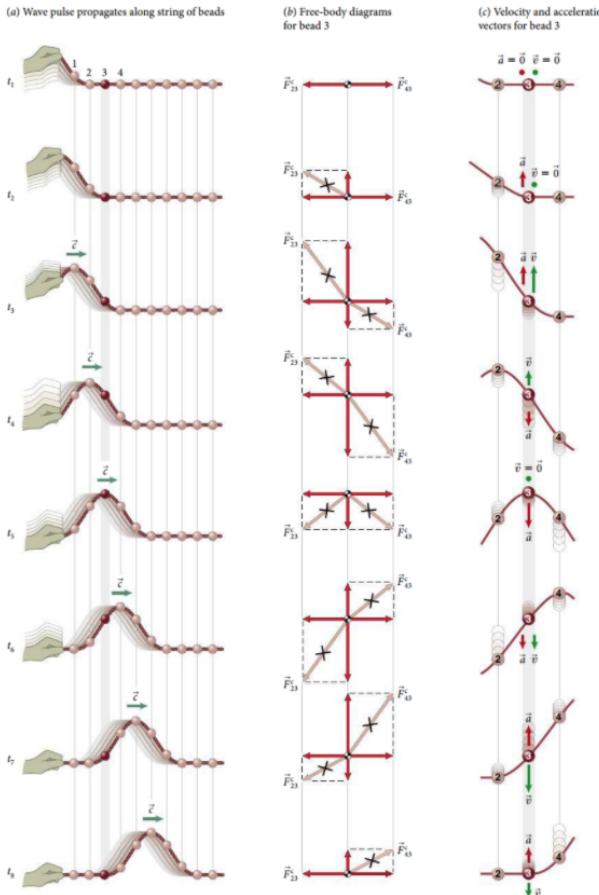
-If displaced the over way



Mazur 16.2 Wave Propagation

-Forces on adjacent beads

Figure 16.7 Forces and accelerations that cause a wave pulse to propagate along a string of beads.



-Wave properties

-c determines v & a

When a particle of the string is displaced from its equilibrium position, its velocity \vec{v} and acceleration \vec{a} are determined only by the initial disturbance and are independent of the wave speed c.

-if everything else is same, higher c = longer pulse

For a given disturbance, high wave speeds yield wave pulses that are stretched out and low wave speeds result in pulses that are more compressed.

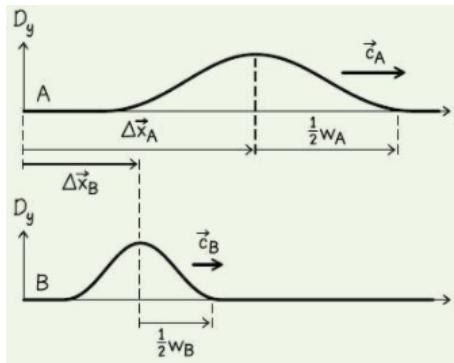
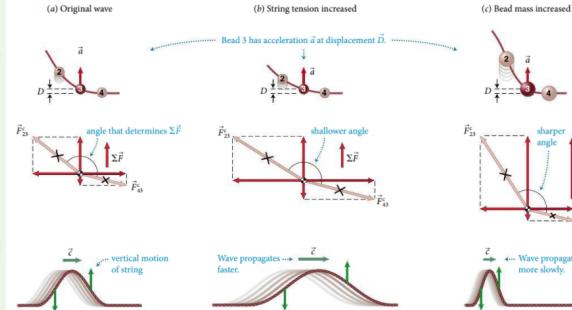


Figure 16.8 Effects of tension and mass on wave speed. (a) The free-body diagrams show the angle between \vec{F}_{T1} and \vec{F}_G , that is required to cause an acceleration \vec{a} at a displacement D . (b) When the tension is greater, a shallower angle is required to produce the same condition so the wave propagates faster. (c) When the mass is greater, a sharper angle is required to produce the same condition so the wave propagates more slowly.



-more tension ($F = N$) increases c, while more mass per length ($\mu u = \text{kg/m}$) decreases c

The speed c of a wave propagating along a string

increases with increasing tension in the string and

decreases with increasing mass per unit length along the string.

$$c = \sqrt{\frac{F}{\mu}}$$

D:

-Rope & mass hanging from ceiling wave speed

A heavy rope is hanging by one end from the ceiling with a block hanging from the other end.

A segment of the rope at the top is supporting not only the weight of the block, but also the weight of the length of the rope below that segment. Thus the tension is greater near the top, and therefore the wave speed is also greater near the top.

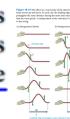
-Wavelength (SI: m)

The wavelength of a periodic wave is equal to the product of the wave speed and the period of the wave motion.

$$\lambda = cT = \frac{2\pi}{B} \quad y = A \sin(B(x + C)) + D \quad f = \frac{c}{\lambda}$$

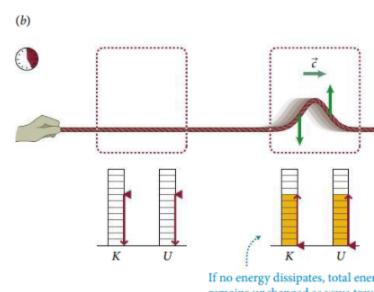
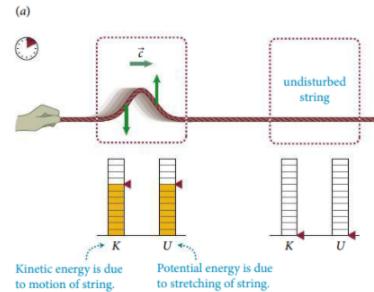
-c is determined by the medium

The speed c of a wave propagating along a string is independent of the velocities \vec{v} of the individual pieces of string. The value of c is determined entirely by the properties of the medium.



-Energy

Figure 16.11 A wave pulse carries kinetic and potential energy. If there is no energy dissipation, the amount of energy in (b) is the same as that in (a).



Mazur 16.5 Wave Functions

-Simple wave with sin (ϕ_i is init phase)

$$D_y = f(x, t) = A \sin[k(x - ct)] = A \sin(kx - \omega t + \phi_i)$$

- k = wave constant (m^{-1}), λ = wavelength

$$k = \frac{2\pi}{\lambda}$$

-wavelength

$$\lambda = cT \quad \lambda f = c.$$

-From that, angular vel

$$kc = \frac{2\pi}{T} \equiv \omega$$

Mazur 16.7 Wave Speed

-Linear mass per length

where μ is the mass per unit length, or **linear mass density**, of the string. For a uniform string of length ℓ and mass m , the linear mass density is

$$\mu \equiv \frac{m}{\ell} \quad (\text{uniform linear object}). \quad (16.25) \quad \mu = \frac{F}{c^2}$$

-Sum of force acting on a segment of string = change in momentum over time

$$\sum \vec{F}_B = \frac{\Delta \vec{p}_B}{\Delta t} = \frac{\mu(c\Delta t)\vec{v}}{\Delta t} = \mu c \vec{v}.$$

-Horizontal Force = Vertical Force

$$\frac{F_{ABy}^c}{F_{ABx}^c} = \frac{F_{ABy}^c}{T} = \frac{vt}{ct} = \frac{v}{c} \rightarrow \sum F_y = F_{ABy}^c = \frac{Tv}{c}$$

$$c = \sqrt{\frac{T}{\mu}}$$

3.13 Exercises: Wave motion

-Spacial and Time harmonic wave function (negative in sin param is to make the wave go right as t increases)

- a = amplitude

- b & c are just constants

$$f(x, t) = a \sin(b(x - ct))$$

$$bx = 2\pi \quad (\text{full cycle spatial})$$

$$b\lambda = 2\pi \quad (\because x=\lambda) \quad f(x, t) = a \sin(bx - \omega t)$$

$$\lambda = \frac{2\pi}{b}$$

$$bx = 2\pi \quad (\text{full cycle spatial})$$

$$b\lambda = 2\pi \quad (\because x=\lambda)$$

$$bct = 2\pi \quad (\text{full cycle time})$$

$$bcT = 2\pi \quad (\because t=T)$$

$$T = \frac{2\pi}{bc}$$

$$\lambda = \frac{2\pi}{b}$$

$$bct = 2\pi \quad (\text{full cycle time})$$

$$\omega T = 2\pi \quad (\because t=T)$$

$$f = \frac{1}{T}$$

$$\omega T = 2\pi = \frac{\omega}{f}$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

- b (aka k) here is the Wave Number (rad/m)

-Power to Sustain a wave ω

$$P = \frac{1}{2} \mu A^2 \omega^2 \frac{\lambda}{T} = \frac{1}{2} \mu A^2 \omega^2 \lambda f$$

-Speed of sound waves in air is about $c=343$ m/s

Wave Reflection <https://www.youtube.com/watch?v=ZxlyptT1FY>

-Fixed End Boundary, the point connecting the end of the string can't move.

-Reflected waves become inverted, so the superposition when the imaginary 2nd wave cross would be Destructive Interference.

-Free End Boundary, the string's end can move.

-Reflected wave isn't inverted, the superposition is Constructive Interference, the wave near the boundary has a spike in amplitude since the wave's peak makes it twice the peak opposed to the singular wave.

Standing Waves https://upload.wikimedia.org/wikipedia/commons/8/86/Standing_Wave_Sum.gif

Figure 16.36 When a harmonic wave is reflected from the fixed end of a string, the reflected wave interferes with the incident wave, forming a standing wave.

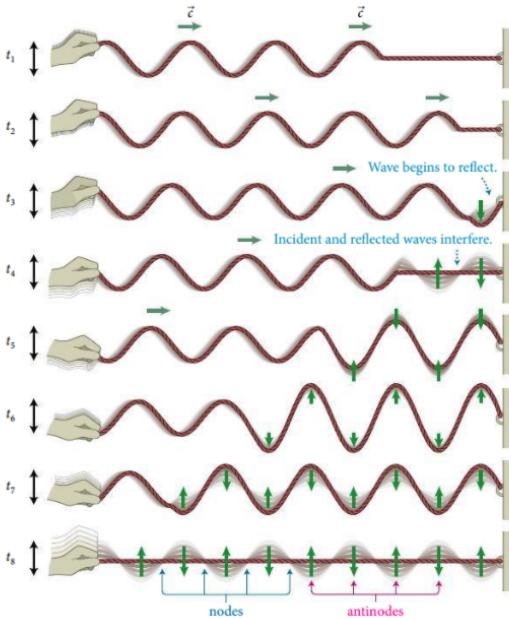
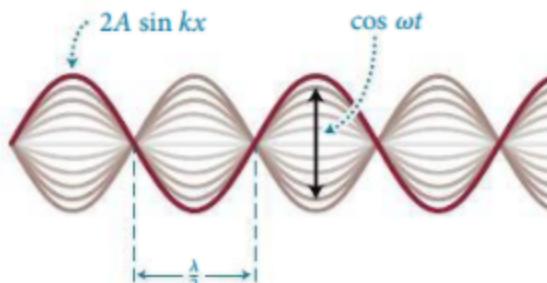


Figure 16.38 A standing wave is a stationary harmonic wave with an amplitude that varies like a sine. The spacing between adjacent nodes is equal to $\frac{\lambda}{2}$.



-Waves that change their amplitude in a cycle as time continues. So they look like it's vibrating up and down.

-Modelled by having 2 identical harmonic waves that have opposite direction wave speed.

-Simplifies to this $y(x, t) = [2A \sin(kx)] \cos(\omega t)$ $\alpha = kx$ and $\beta = \omega t$

-The points of the wave that's always 0 as time continues are called Nodes.

-Between the nodes are the vibrating amplitude parts, called Antinode.

-The max of the Antinode/amplitude is in the midpoint between the Nodes and is the superposition of the amplitude of both original waves.

-The nodes are always spaced evenly like this for a standing wave. They occur when $\sin(kx)=0$

$$\begin{aligned} \sin(kx) &= 0 \\ kx &= 0, \pi, 2\pi, 3\pi, \dots \\ \frac{2\pi}{\lambda}x &= 0, \pi, 2\pi, 3\pi, \dots \\ x &= 0, \frac{\lambda}{2}, \lambda, \frac{3\lambda}{2}, \dots = n \frac{\lambda}{2} \quad n = 0, 1, 2, 3, \dots \end{aligned}$$

-Standing wave IRL only occur when the wavelength is a division of the medium's length



-Longest possible (fundamental) wavelength of Standing Wave (From f & c => λ & length => fundamental freq)

-Both Fixed/Open Ends (Ends are nodes)

For strings that are fixed at both ends (like all stringed instruments) and pipes or tubes that are either closed at both ends or open at both ends, the relationship between the physical length L of the string or pipe and the longest possible wavelength of a standing wave in or on it is $\lambda = 2L$, but it is also possible to have shorter wavelengths fit... integer divisions of $2L$: $\frac{2L}{2}, \frac{2L}{3}, \frac{2L}{4}, \dots$

-One Fixed & One Open (One end is node, another is mid of antinode. Then the length of the system is 4x as long as length of the ends) (Odd Harmonics)
It's a little more strange for a string or pipe where one end is fixed and one is open (or free). Then, the fundamental (or longest) wavelength is equal to four times the length of the physical object, and the shorter wavelengths (or harmonics) are only the odd harmonics: $4L, \frac{4L}{3}, \frac{4L}{5}, \frac{4L}{7}, \dots$

$$\lambda = 4L$$

-Wind instrument be like

Mazur 17.1 Wavefront

-Surface Wave: a wave that propagate 2D

Figure 17.2 Top view of the circular crests and troughs formed in a periodic surface wave. We represent the wave schematically as a series of wavefronts.

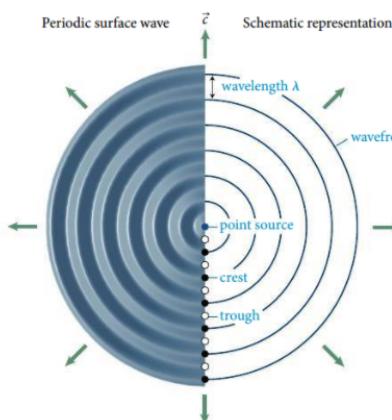
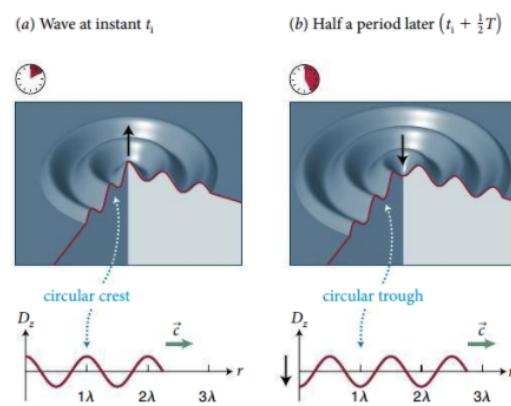


Figure 17.1 Cutaway views of a wave on the surface of a liquid and the corresponding vertical displacement of the surface as a function of distance r from the oscillating wave source, which is located at $r = 0$.

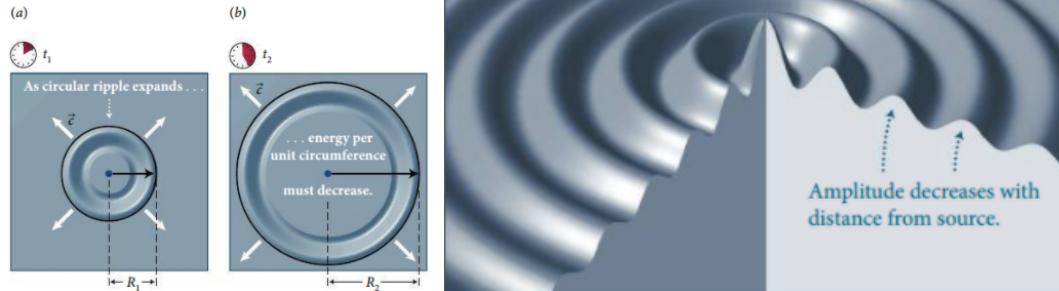


-Since the ripples are circularly symmetrical. The 2D slices are the same all around

-Energy and wave's radius/circumference from point source

-Therefore, without a consistent point source to add energy, the amplitude decreases the further out travelled.

Figure 17.3 A surface wave moving at speed c . Because surface waves expand in two dimensions, the wave energy is distributed over a larger and larger circumference.



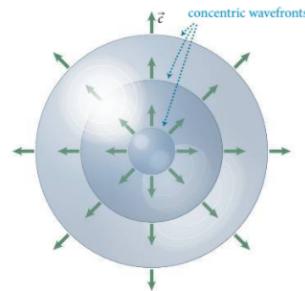
$$A = 1/\sqrt{r}$$

$$\text{Energy per unit length} = 1/r \text{ (UNSURE)}$$

$$E_\lambda = \frac{1}{2}\mu\lambda\omega^2 A^2$$

-Wavefront in 3D: Spheres

Figure 17.5 The wavefronts from a point source emitting waves in three dimensions are uniformly expanding, concentric spheres.



$$A = 1/r$$

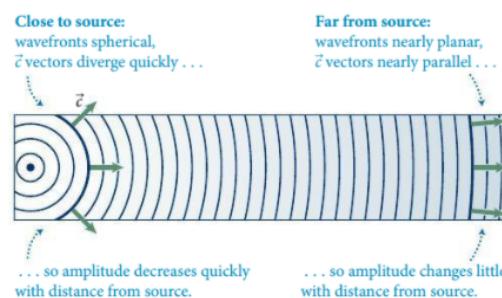
$$\text{Energy per unit area} = 1/r^2$$

-Wavefronts Amplitude

The amplitude of waves in two dimensions decreases with distance r from the source as $1/\sqrt{r}$; in three dimensions it decreases as $1/r$. This decrease is due purely to the spreading out of the wavefronts and involves no loss of energy.

-Wavefronts further from sources is good approximately a planar wavefront

Figure 17.7 Far from the source, wavefronts are nearly flat, so amplitude changes little with additional distance from the source.



Mazur 17.2 Sound

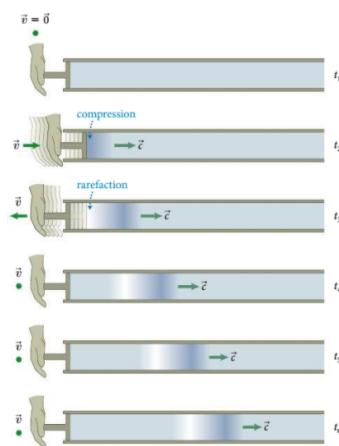
-Sound

-Waves that propagate through any medium that can exert elastic restoring force (or use it gets dented like bonked dog)

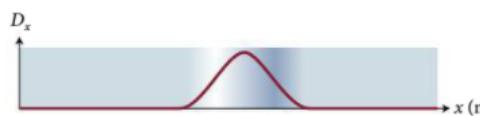
-A Compression Wave

Figure 17.8 A piston generates a longitudinal sound pulse that propagates along an air-filled tube. The disturbance consists of a compression and a rarefaction. The wave function is similar to the one for a longitudinal wave in a spring (see Figure 16.6).

(a) Longitudinal wave pulse created by in-and-out movement of piston



(b) Wave function of pulse at instant t_6



-Standing Wave and Sound

-When a string vibrates up and down, it pushes the air around it, making the air vibrate at the same frequency as the standing wave.

-Since the wave speed of the string is not the same as air, the wavelengths will be different too.

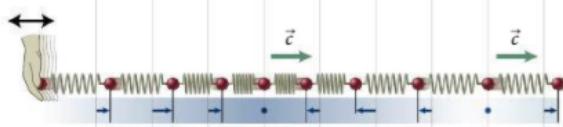
-The wave in the pic is a Longitudinal Wave. Here's a model (Compression and Rarefaction are flipped)

Figure 17.9 A simple mechanical model for longitudinal waves.

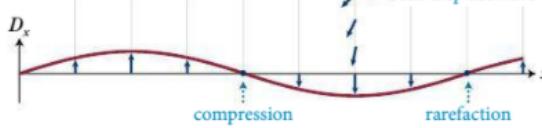
(a) Identical beads coupled by springs



(b) Snapshot of longitudinal wave propagating along chain



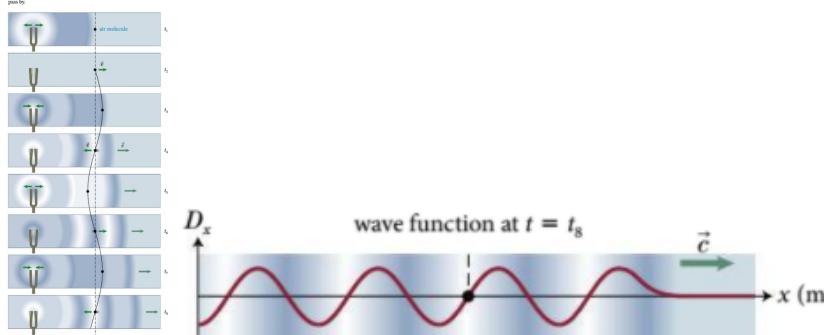
(c) Corresponding wave function



The compressions and rarefactions in longitudinal waves occur at the locations where the medium displacement is zero.

-Tuning Fork Ex

Figure 17.10 The periodic wave emitted by a tuning fork causes a series of alternating compressions and rarefactions in the air molecules that oscillate about their equilibrium position as the wavefront passes by.



Mazur 17.5 Intensity

-Intensity 3D (SI: W/m^2)

$$I \equiv \frac{P}{A} \quad (\text{P is power delivered/generated by source, A is area})$$

$$I = \frac{P_s}{A_{\text{sphere}}} = \frac{P_s}{4\pi r^2} \quad (\text{uniformly radiating point source})$$

-Intensity 2D (SI: W/m)

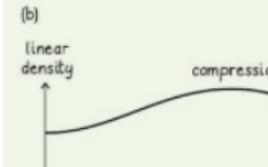
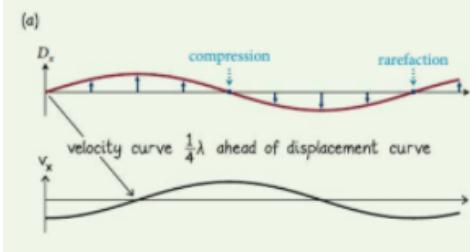
$$I_{\text{surf}} \equiv \frac{P}{L}$$

-Intensity Level aka Decibel Rating (not really SI: decibel (dB)) (This is intensity but scaled to Human hearing, where 0dB is I_th, the threshold of hearing)

$$\beta \equiv (10 \text{ dB}) \log \left(\frac{I}{I_{\text{th}}} \right) \quad \text{where } (I_{\text{th}} = 10^{-12} \text{ W/m}^2)$$

$$\text{Intensity from dB: } I = 10^{\frac{\beta}{10}} I_{\text{th}} = 10^{\frac{\beta}{10}} 10^{-12}$$

Figure S17.4



-Cool graph of human tolerable intensity level that's trivial probably

Figure 17.26 Average auditory response of the human ear. The ear is sensitive to longitudinal waves in air ranging in frequency from 20 Hz to 20 kHz. The sensitivity is greatest at 3 kHz, where the threshold of hearing is lowest. The curves give the intensity levels required to produce harmonic tones of the same perceived loudness.

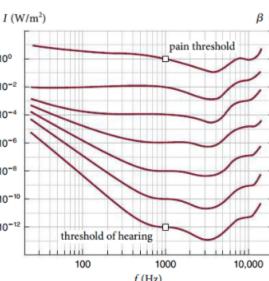


Table 17.1 Approximate intensity levels

Source	distance (m)	β (dB)	Description
Jet engine	50	140	pain
Pneumatic hammer	10	110	
Shout	1.5	100	very loud
Car horn	10	90	
Hair dryer	0.2	80	loud
Automobile interior		70	
Conversation	1	60	moderate
Office background		50	
Library background		40	
Suburban bedroom		30	quiet
Whisper	1	20	
Normal breathing	5	10	barely audible

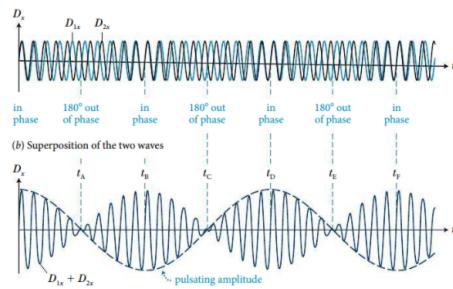
Mazur 17.6 Beats

-Beating (typical DnB bass be like)

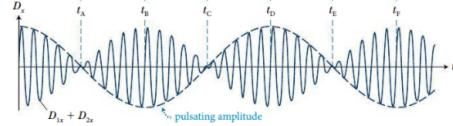
-Detune the freq a little bit, and the amplitude pulsate.

Figure 17.27 When two sources emit waves of equal amplitude but slightly different frequencies, the waves superpose to produce a wave that has a pulsating amplitude (dashed line). We call this phenomenon *beating*.

(a) Displacement curves for two waves of equal amplitude but slightly different frequencies



(b) Superposition of the two waves



-Beat Frequency (f of pulsating amplitude)

$$f_{\text{beat}} \equiv |f_1 - f_2| \quad \text{OR if u dont know which is higher in frequency } f_{\text{beat}} = f_1 \pm f_2$$

Mazur 17.7 Doppler Effect

-So, it's like u playing Tow House.

-When u shoot and get closer to the enemy, the f of the bullets is higher than emitted f.

-When u shoot and get further from the enemy, the f of the bullets is less than emitted f.

Source receding:

$$f_{\text{observed}} = \left[\frac{v}{v + v_{\text{source}}} \right] f_{\text{source}}$$

Source approaching:

$$f_{\text{observed}} = \left[\frac{v}{v - v_{\text{source}}} \right] f_{\text{source}}$$

This is from $\frac{c}{\Delta\lambda}$

-Fat table of Doppler Effect sign to use when calculating

Doppler shift $f_o = f_s \left(\frac{v \pm v_o}{v \mp v_s} \right)$	Stationary observer	Observer moving towards source	Observer moving away from source
Stationary source	$f_o = f_s$	$f_o = f_s \left(\frac{v + v_o}{v} \right)$	$f_o = f_s \left(\frac{v - v_o}{v} \right)$
Source moving towards observer	$f_o = f_s \left(\frac{v}{v - v_s} \right)$	$f_o = f_s \left(\frac{v + v_o}{v - v_s} \right)$	$f_o = f_s \left(\frac{v - v_o}{v - v_s} \right)$
Source moving away from observer	$f_o = f_s \left(\frac{v}{v + v_s} \right)$	$f_o = f_s \left(\frac{v + v_o}{v + v_s} \right)$	$f_o = f_s \left(\frac{v - v_o}{v + v_s} \right)$

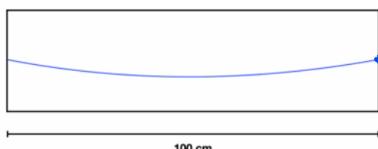
where f_o is the observed frequency, f_s is the source frequency, v is the speed of sound, v_o is the speed of the observer, v_s is the speed of the source, the top sign is for approaching and the bottom sign is for departing.

Lab 4 Collab Standing Waves

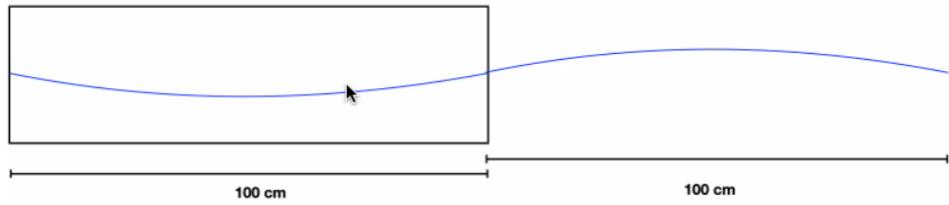
-At what f will the standing wave happen?

-Wavelengths that fit example

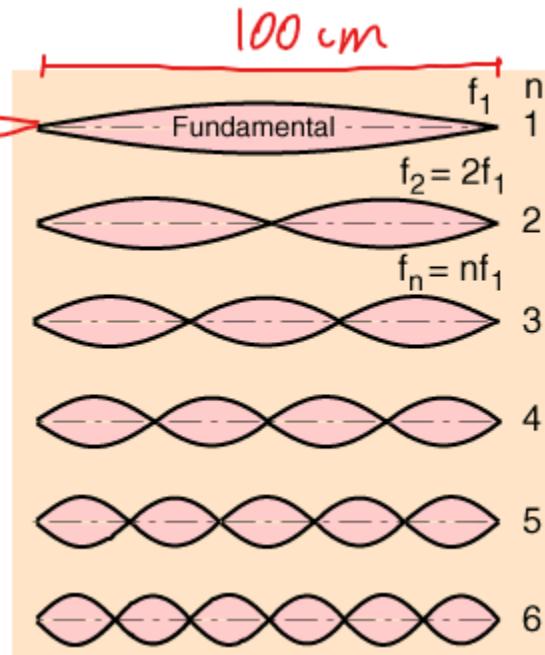
Practice: What wavelengths will "just fit"?



The longest wave...

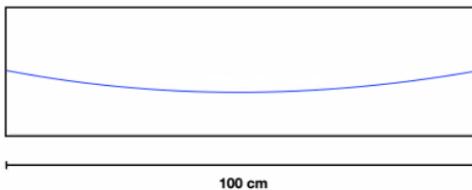


- If both ends are fixed, that means there have to be nodes at both ends.
- What wavelengths would fit between two fixed ends that are 100 cm apart?



-With frequency $\lambda=c/l$ where l is increment of 1 to keep nodes at 100 cm intervals.

Practice: What wavelengths will "just fit"?



- If both ends are fixed, that means there have to be nodes at both ends.
- What wavelengths would fit between two fixed ends that are 100 cm apart?
- If the wave speed is 160 cm/s...
- ... what frequencies would produce standing waves?

x	$N \frac{c}{(\frac{l}{x})}$
0	0
1	0.8
2	1.6
3	2.4
4	3.2
5	4
6	4.8
7	5.6
8	6.4
9	7.2
10	8

-The frequency is increasing by 0.8 Hz per node (same as Hz for fundamental).

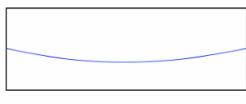
-With higher frequency, the amplitude is less because you need more energy to make those higher frequency waves (higher f is mathematically the same as higher c).

If the wave speed is 220 cm/s...

1	1.1
2	2.2
3	3.3
4	4.4
5	5.5
6	6.6
7	7.7
8	8.8
9	9.9
10	11

-Length changed

What if the length of the system changes?

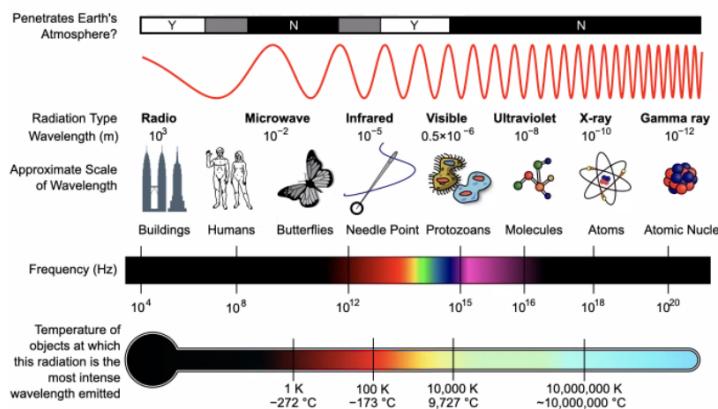


(therefore the length is 160)

1	1.375
2	2.75
3	4.125
4	5.5
5	6.875
6	8.25
7	9.625
8	11
9	12.375
10	13.75

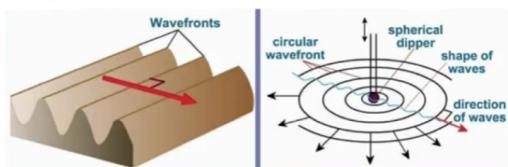
5.2 Light and reflection

-Chart of EM Wave Frequencies



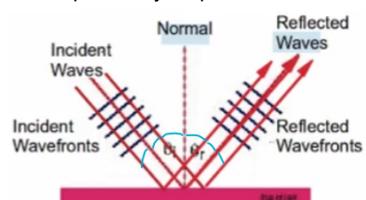
-Ray Model of Light

- Similar to treating light as a particle... it travels in straight lines and can bounce and bend when it reaches boundaries.
- Can also be viewed as treating light as a series of wavefronts... the ray traces the direction of the wavefront and is therefore perpendicular to the wavefront.

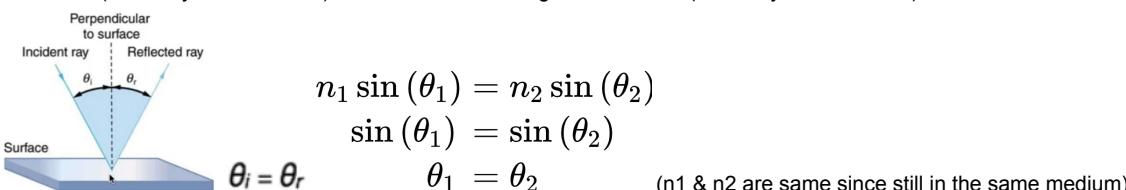


-Reflection

-The light bounce, specularity map wow.

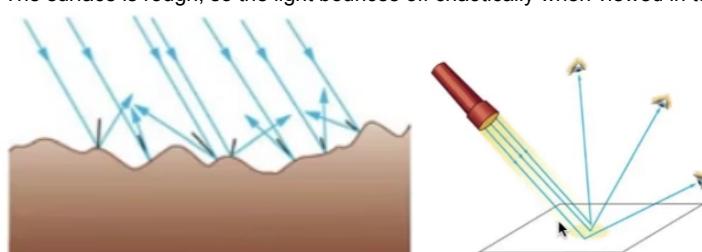


-Angle of the incident (wave/ray to the normal) is the same as the angle of reflection (wave/ray to the normal)

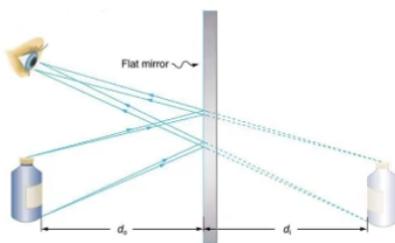


-Diffuse reflection

-The surface is rough, so the light bounces off chaotically when viewed in total.

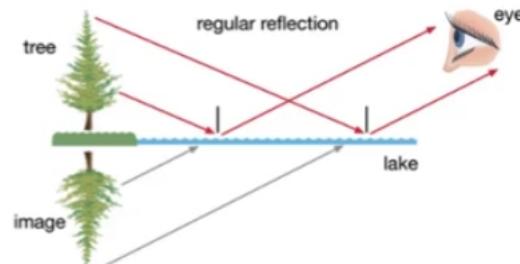
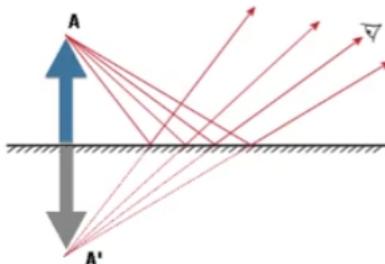


-Mirror (very smoothed polished material)



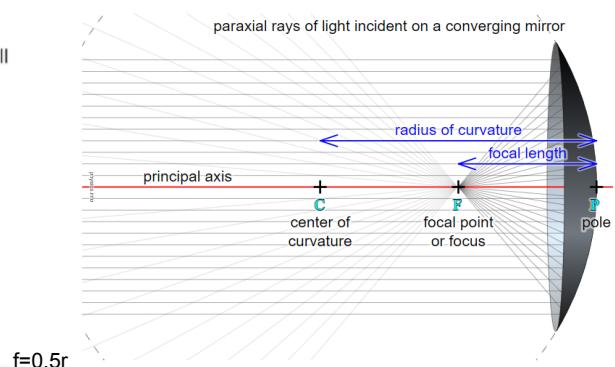
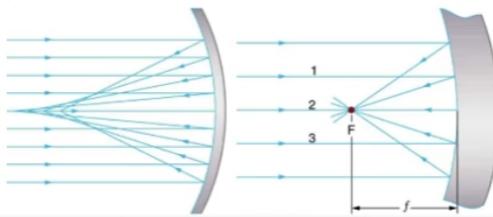
-Ray diagram

- Use lines drawn in specific ways to determine the reflected image



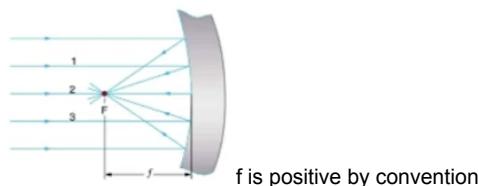
-Curved Mirror

- Applying the law of reflection at each point along a curved surface shows that parallel incident rays are reflected back through a central area.
- If the mirror itself is small relative to the radius of curvature, that area is small enough to be called a focal point.
- The distance f is called the focal distance and is equal to half the radius of curvature.

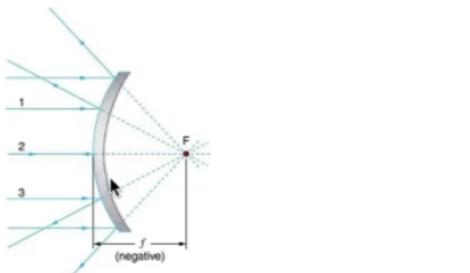


-Concave and Convex mirror

-Concave (like a cave)



-Convex (light coming from left btw)



f is negative by convention

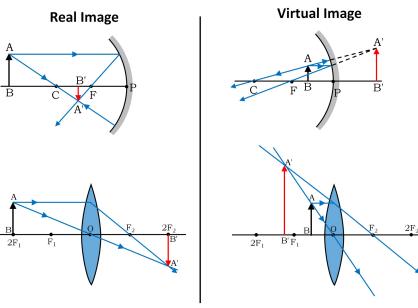
-Big juicer culmination of reflection as equation & Real VS Virtual Image (Real is inverted, Virtual is upright)

If the distance from the object to the plane of the mirror is o , and the focal length is f , an image is formed at i where

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

$$\frac{1}{d_f} = \frac{1}{d_o} + \frac{1}{d_i}$$

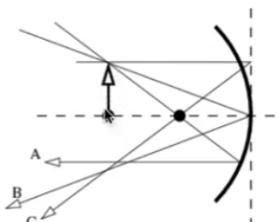
$$\text{magnification } m = -\frac{i}{o} \text{ or } -\frac{d_i}{d_o}$$



-Magnification (negative sign there btw) allows you to calculate the height of the image (and object be going reversed)

-Ray Diagram RULES

- Incident light rays parallel to the principal axis of a mirror are reflected through the focal point (or appear to be). (C here and red lines on next diagrams)
- Incident rays that pass through the focal point are reflected parallel to the principal axis. (A here and blue lines on next diagrams)
- Incident rays that strike the centerline are reflected back at an equal angle. (B here and black lines on next diagrams, though only the reflected ray is shown to reduce clutter)
- Incident rays that pass through the center of curvature are reflected back through the center of curvature. (not shown here, but these are the green lines on the next diagrams)



-Example Concave (Behind radius of curvature)

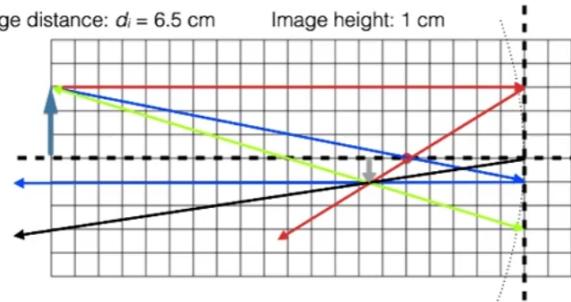
Focal length: $d_f = 5 \text{ cm}$

Object distance: $d_o = 20 \text{ cm}$

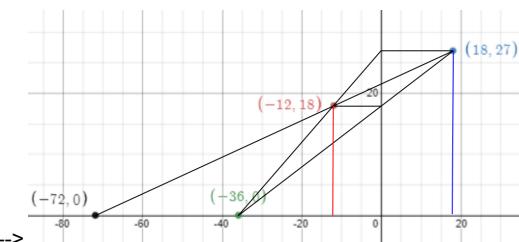
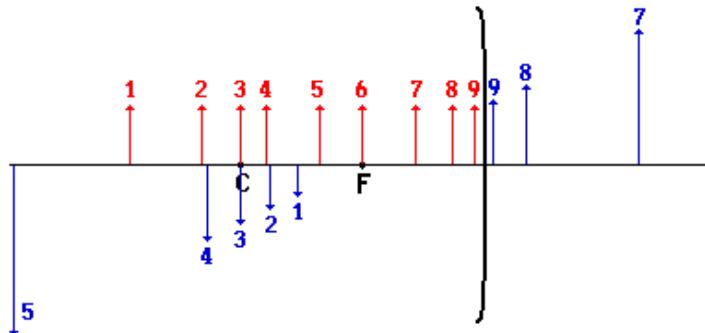
Object height: 3 cm

Image distance: $d_i = 6.5 \text{ cm}$

Image height: 1 cm

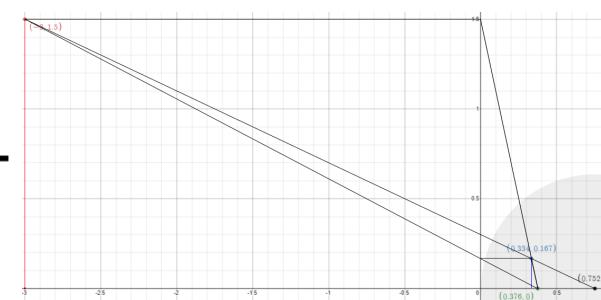
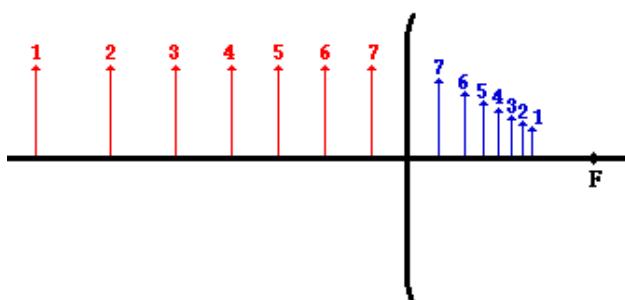


-Concave Reflected Image possibilities (red is the object, blue is the corresponding image) Physicsclassroom



For cases 7,8,9 --->

-Convex Reflected Image possibilities (red is the object, blue is the corresponding image) (There's only, the image is virtual and upright)



5.6 Electromagnetic waves

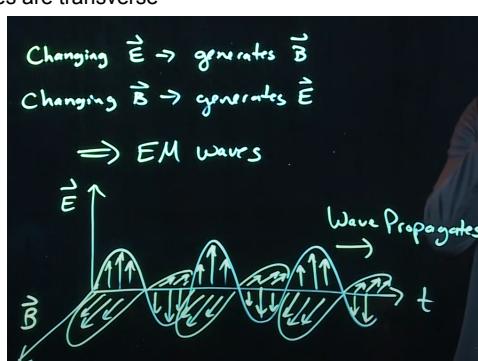
-Speed of light again (c_{naught})

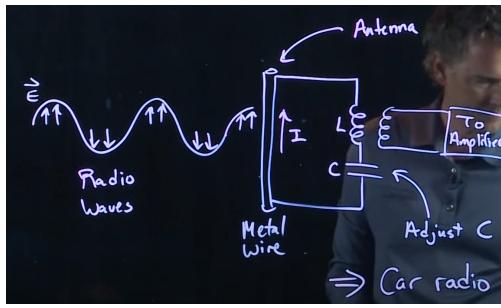
$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \text{ m/s}$$

-Magnitude of Electric and Magnetic field relationship

$$E = cB$$

-EM Waves are transverse





-The length of the antenna is 1/2 the wavelength.

-Freq and Wavelength Relationship (& list of refractive indices) ($c=c_0/n \rightarrow$ wave speed = speed of light / refractive index)

Every frequency of electromagnetic wave has an associated wavelength in a particular medium given by the formula $\lambda = \frac{c}{n}$, where v is the wave speed in that medium. For a vacuum (no medium) the wave speed is c . Recall that for other media, the wave speed is $v = \frac{c}{n}$, where n is the index of refraction of the medium.



FAT TYPO! $\lambda = \frac{c}{f}$

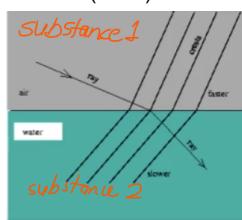
-Big juicer joy [link](#) summary

6.2 Refraction

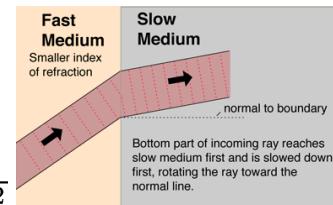
-Refraction

-The change in direction of the light ray when it enters a new medium

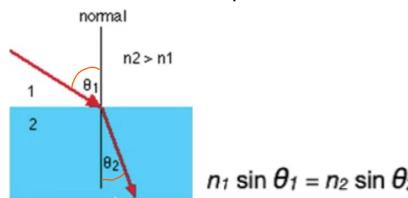
-Index of refraction ($n > 1$)



$$n_1 = \frac{\text{speed of light in a vacuum}}{\text{speed of light in substance 1}} \quad n_2 = \frac{\text{speed of light in vacuum}}{\text{speed of light in substance 2}}$$

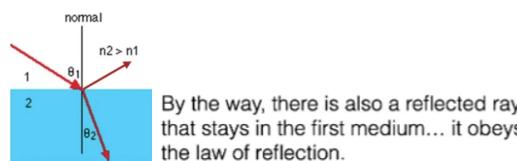


-Refraction's sinusoidal relationship



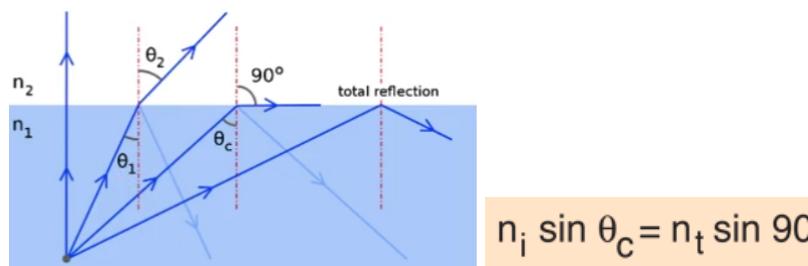
If light goes from less dense to more dense material, it 'bends toward the normal'. If light goes from more dense to less dense material, it 'bends away from the normal'.

-Reflection with Refraction



(The intensity of reflection + reflection = original)

-Total internal reflection (More dense into less dense)



-Snell's Window

-Lenses

If the distance from the object to the plane of the mirror is o , and the focal length is f , an image is formed at i where

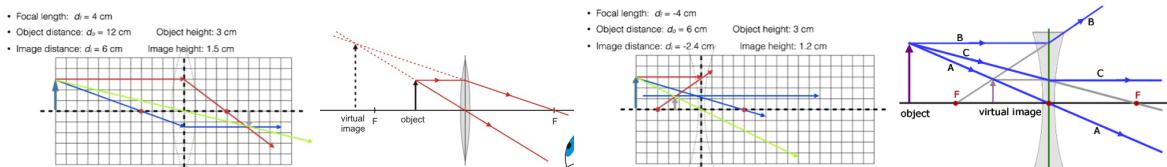
$$\frac{1}{d_f} = \frac{1}{d_o} + \frac{1}{d_i}$$

-Ray Diagram

- Incident light rays parallel to the principal axis of a mirror are refracted through a focal point (or appear to be).
- Incident rays that pass through the focal point are refracted parallel to the principal axis.
- Incident rays that pass through the centerline go straight through the lens.
- (There is no center-of-curvature ray.)

-Virtual Image is on same side.

-Examples (2 Con, 2 Div)

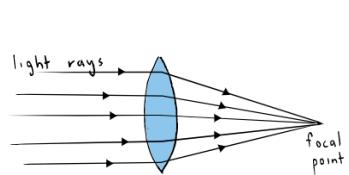


-Wavelength and Index of Refraction

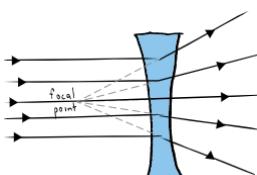
$$n_i \lambda_i = n_r \lambda_r \text{ (The frequency stays the same for incident and refraction)}$$

-Type of Thin Mints Lens

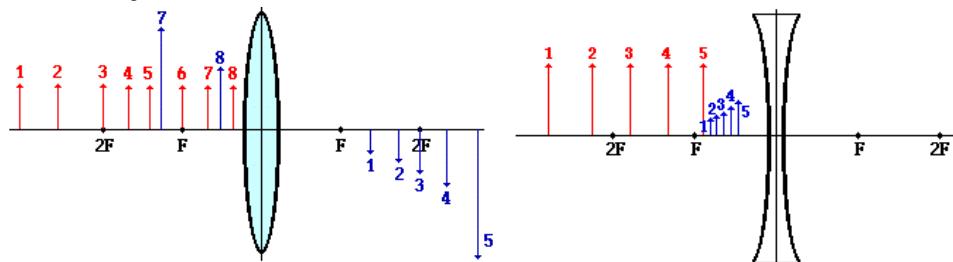
-Converging



-Diverging



-Physicsclassroom coming in clutch



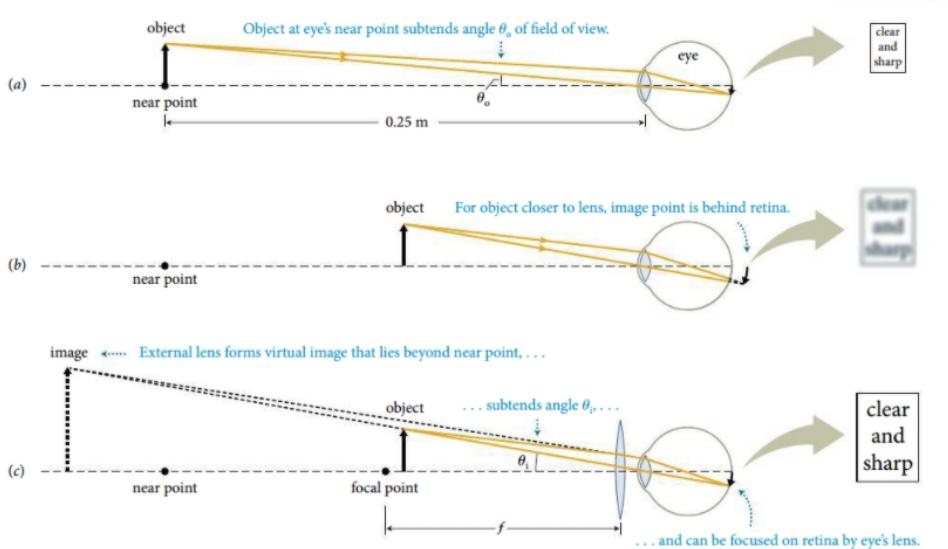
-Sign convention for Thin Mints Lens VS Mirror

Table 33.2 Sign conventions for f , i , and o (positive = real; negative = virtual)

Sign	Lens	Mirror
$f > 0$	converging lens	converging mirror
$f < 0$	diverging lens	diverging mirror
$o > 0$	object in front ^b of lens	object in front of mirror
$o < 0^a$	object behind lens	object behind mirror
$i > 0$	image behind lens	image in front of mirror
$i < 0$	image in front of lens	image behind mirror
$h_i > 0$	image upright	image upright
$h_i < 0$	image inverted	image inverted
$ M > 1$	image larger than object	image larger than object
$ M < 1$	image smaller than object	image smaller than object

-Eyeball, Lenses, Near Point

Figure 33.45 An eye cannot focus on an object that is closer than its near point (which represents the limit of the biological lens's ability to change curvature). However, an external converging lens (such as a magnifying lens) makes it possible to see objects that are closer than the near point. It also enlarges them.

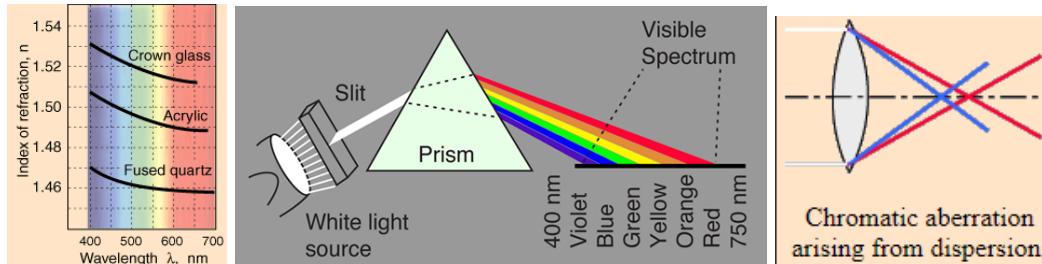


6.3 Prism

-EM travel at different speeds in different substances.

-Dispersion

-High freq light (lower refraction index) bend more than lower freq light.



-Light enters a different medium, it then bends to the refraction angle. When it leaves the medium it bends back to the angle of the incident.

6.4 Diffraction and interference

-Light is a wave.

-That means there can be interference!

-Water representation of the double-slit experiment. The two sources of waves cancel each other out (antinodal lines), and also constructively make larger waves (nodal lines).

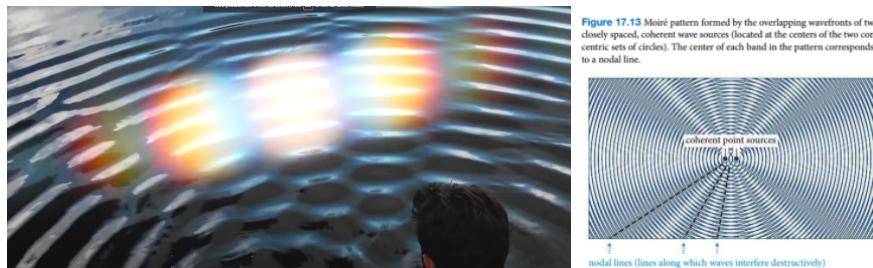
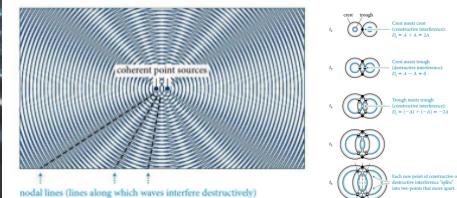


Figure 17.11 The effect of changing the separation between two point sources.

Figure 17.12 Interference of two identical sets of circular wave pulses originating from a liquid surface.



If two coherent sources located a distance d apart emit identical waves of wavelength λ , then the number of nodal lines on either side of a straight line running through the centers of the sources is the greatest integer smaller than or equal to $2(d/\lambda)$.

-Diffraction

-Waves "bend"/spread out around corners. Waves traveling through different openings have different results.

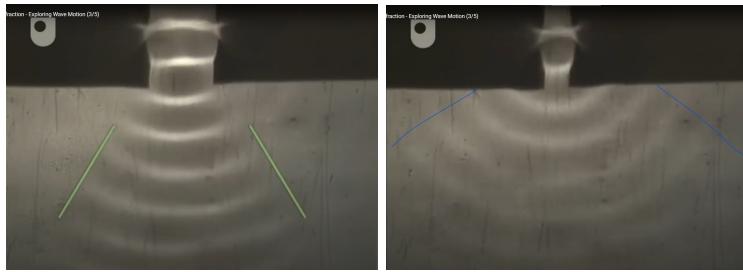
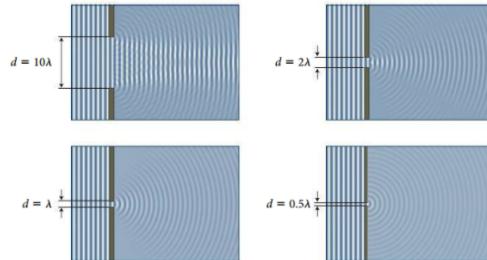


Figure 17.22 When a planar wavefront passes through a gap, some spreading, called diffraction, occurs. The smaller the gap, the greater the amount of spreading. When the width d of the gap is smaller than the wavelength λ , the gap acts like a point source.

17.12 See **Figure S17.12**. A narrow gap causes diffraction regardless of the orientation of the incident wavefronts because the incident waves cause the gap to become a point source. (For simplicity the reflections of the planar wavefronts from the back surface of the barrier have been omitted from the drawing.)

Figure S17.12



-Narrower opening = bigger spread.

-Smaller wavelength (higher freq), less diffraction and viceversa.

-More accurately, when the gap is smaller than the wavelength, it acts like a point source, super-duper diffraction.

Obstacles or apertures whose width is smaller than the wavelength of an incident wave give rise to considerable spreading of that wave.

Mazur 33.8 Lens Maker Formula

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

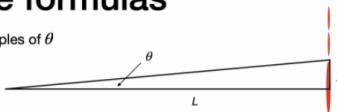
Our derivation was for a double-convex lens, but it can be shown that the lensmaker's formula applies to any thin lens, not just a double-convex lens. The radii of curvature are positive for convex surfaces, negative for concave surfaces, and infinity for planar surfaces. For a double-convex lens, f is positive. For a double-concave lens, f is negative (because $n > 1$ for any material used for lenses).

Collab 6 Double Slit

The formulas

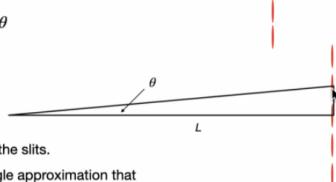
- Single slit minima are found at multiples of θ

$$\sin \theta = \frac{\lambda}{a} \quad \text{and} \quad \tan \theta = \frac{y}{L}$$



- Double slit maxima are found at multiples of θ

$$\sin \theta = \frac{\lambda}{d} \quad \text{and} \quad \tan \theta = \frac{y}{L}$$



For single slits, a is the width of the slit.

For double slits, d is the separation between the slits.

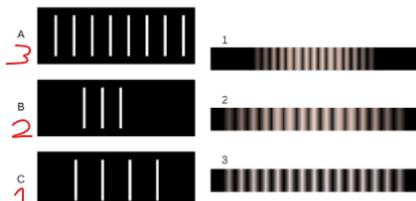
If the angle is small, we can use the small angle approximation that

$$\sin \theta = \tan \theta = \theta \quad \text{so we can write} \quad \frac{\lambda}{a} = \frac{y}{L} \quad \text{or} \quad \frac{\lambda}{d} = \frac{y}{L}$$

-Single slit has double width pattern of the centerline.

-More than the 2 slits

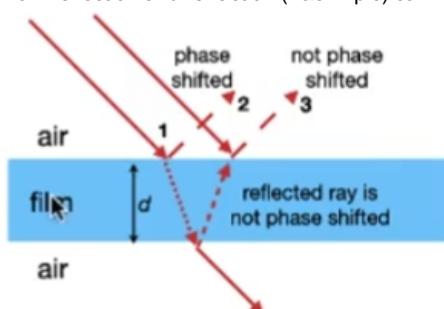
-More slits = more narrow, less blurry.



6.8 Light as a wave

-Thin film (<http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/oilfilm.html#c1>)

-Light waves from reflection and refraction (2&3 in pic) can interfere with each other since some reflection causes phase shift.



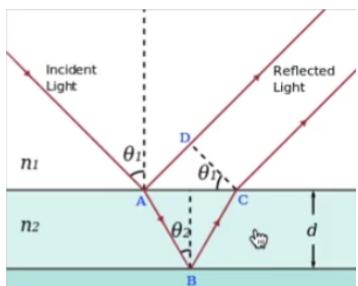
$$2d \cos \beta = \lambda_x = \frac{\lambda}{n_x} \quad (\text{lambda}_x \& n_x \text{ is of the not air medium})$$

Constructive interference will happen if the distance through the film (about twice the thickness of the film) is an integer multiple of the wavelength in the film:

$$2d \cos \beta = \lambda_x, 2\lambda_x, 3\lambda_x, \dots$$

$$2d \cos \beta = \frac{\lambda}{n_x}, 2\frac{\lambda}{n_x}, 3\frac{\lambda}{n_x}, \dots$$

-Equation different version



Destructive interference will happen if the distance through the film (about twice the thickness of the film) is a "half multiple" of the wavelength in the film:

$$2d \cos \beta = \frac{1}{2}\lambda_x, \frac{3}{2}\lambda_x, \frac{5}{2}\lambda_x, \dots$$

$$2d \cos \beta = \frac{\lambda}{2n_x}, \frac{3\lambda}{2n_x}, \frac{5\lambda}{2n_x}, \dots$$

Interference will be constructive if the optical path difference is equal to an integer multiple of the wavelength of light, λ .

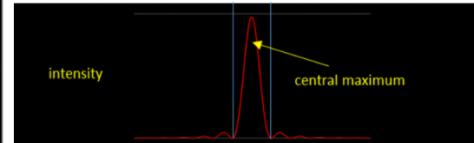
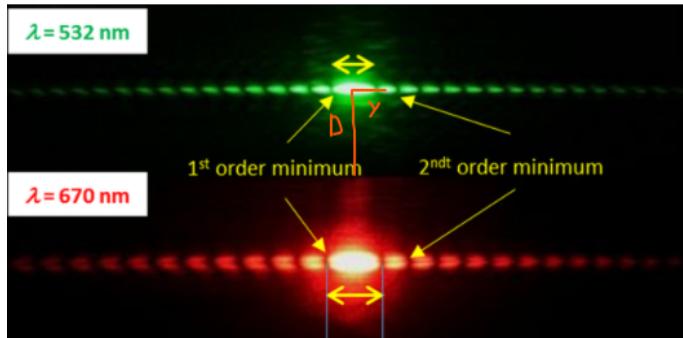
$$2n_2 d \cos (\theta_2) = m\lambda$$

6.9 Single slit interference

$$\sin \theta = \frac{\lambda}{a} \quad \text{and} \quad \tan \theta = \frac{y}{D}$$

(a is the slit/opening spacing. D is distance from the slit to the wall, y is the spread from the center line)

(scroll up lens maker for better)



- The higher the wavelength, the more the spread.
- Higher distance between slits (a), less spread.
- Single slit has a center fringe 2x the fringe spacing (y).
- Double split has minimum order fringes in between the bright order fringes
 - Higher split, more minimum order in between

7.2 Light as particle

- History
 - People believe light is a wave because of diffraction experiments.
 - Maxwell's equation
- Then people believe maybe not?
 - If light is wave, medium?
 - Blackbodies radiation

-Blackbody radiation

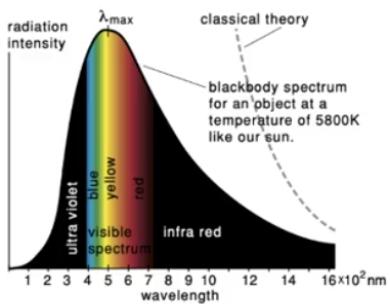


Figure 1
Blackbody spectrum at 5800 degrees on the kelvin scale. The solid line is the experimental curve, the dotted line represents the prediction of Newtonian mechanics combined with Maxwell's equations. The classical theory agrees with the experimental curve only at long wavelengths.

- Experiments showed that when objects were heated to specific temperatures, they emitted a range of frequencies (or wavelengths) of electromagnetic waves.

- For example, at the temperature of our Sun, the blackbody spectrum peaks in the range of visible light.
- (This is not just a coincidence; eyes developed to be sensitive to the energy available in our environment!)
- But Maxwell's equations and classical mechanics could not produce a theoretical curve that came anywhere near fitting the experimental data for blackbody radiation.
- Yet the spectrum did seem to be very predictable. The shape remained the same over a wide range of temperatures, and the maximum wavelength was always about 3×10^{-3} m divided by the temperature in kelvin.

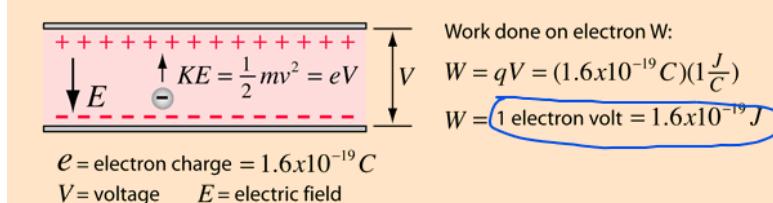
-Maxwell's equation could figure it out

-Planck's Solution to create the curve

- With no reason to justify his approach, Planck noted that he could produce blackbody curves from the classical theories if he restricted the emission (or absorption) of electromagnetic radiation to happen only in discrete chunks.
 - In other words, it appeared that the energy in the radiation was not continuous; it came in packets, and those packets had a minimum size.
 - The mathematics that make the models work resulted in a proportional relationship between the amount of energy in the minimum-size packet and the frequency of the electromagnetic wave: $E = hf$, where h is now called Planck's constant.
- (h= $6.63 \times 10^{-34} \text{ J s}$)

-Electron Volts (eV)

A convenient **energy** unit, particularly for **atomic** and **nuclear** processes, is the energy given to an electron by accelerating it through 1 **volt** of electric potential difference. If an electron starts from rest at the negative plate, then the **electric field** will do work eV on it, giving it that amount of **kinetic energy** when it strikes the positive plate. The work done on the **charge** is given by the charge times the voltage difference, which in this case is:



-Energy of light is related to frequency ($E=hf$)

- Waves transport energy. Planck said that it doesn't transport it continuously, but in discrete amounts.
- Energy of a wave is associated with amplitude, right? Planck's equation says otherwise, it's on frequency. We don't know why, but it works.

$$E = \frac{hc}{\lambda}$$

$$E = \frac{1240 \text{ eV nm}}{\lambda}$$

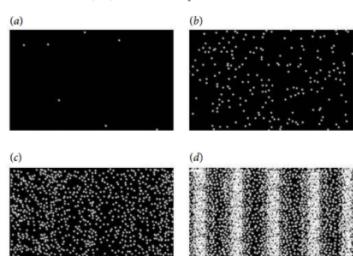
- This formula can also be written in terms of wavelength by using the speed of light.
- If energy is measured in electron volts, there is a nice way to write the quantity hc : 1240 eV nm, so we can also write the energy a third way.

Mazur 34.5 Photons

-Camera experiment

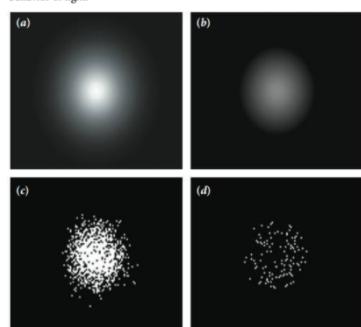
-Electrons shot through a 2-slit experiment accumulates as diffraction pattern

Figure 34.25 When we perform two-slit diffraction with a very weak electron beam, we can see the pattern build up over time. At first (a, b), the dots that mark electron impacts seem to be scattered randomly, but as more accumulate (c, d), the diffraction pattern becomes evident.



-Doing the reversed with light: Turning down intensity of light shining at the camera, it looks like there are particles that hit the camera.

Figure 34.26 Images formed by using the sensor of a digital camera to record increasingly faint beams of light for the same exposure period. The separate dots recorded for the faintest beams reveal the particle-like behavior of light.



-The chance a photon lands is proportional to the intensity of the light at an area.

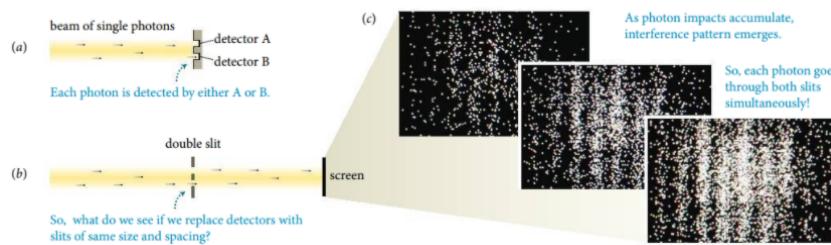
-No half impact, no 2 impacts at once were recorded. Conclusion: A light source shoots out photons.

-The energy of a photon is $E=hf$

-Photons are discrete particles when detected

-In transit, it acts like a wave.

Figure 34.27 When we record a low-intensity beam of light with individual detectors, the beam acts like a stream of particles. Passing it through a double slit, however, causes an interference pattern to emerge.

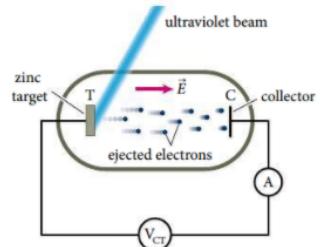


Mazur 34.10 Photon energy and momentum

-Photoelectric Effect

-Shining ultraviolet light at a negatively charged material like zinc in the pic causes it to lose its charge.

Figure 34.47 Apparatus to study the photoelectric effect. The potential difference V_{CT} is positive when $V_T > V_C$.



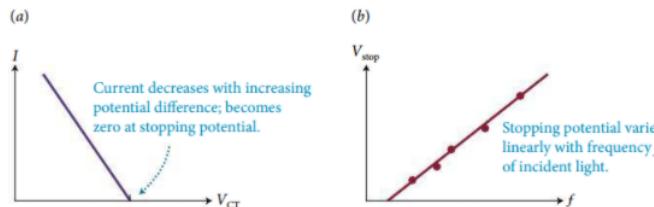
For a given potential difference between the target and the collector, the electric field does work $-eV_{CT}$ on an electron as the electron moves from the target to the collector (see Eq. 25.17). The change in the electron's kinetic energy is thus

$$\Delta K = -eV_{CT}. \quad (34.33)$$

Given that the electrons just barely reach the collector at the stopping potential difference, we know that their final kinetic energy is zero, and so for these electrons $\Delta K = K_f - K_i = -K_i$. The maximum kinetic energy with which the electrons leave the target is thus

$$K_{\max} = K_i = eV_{stop}. \quad (34.34)$$

Figure 34.48 For the circuit in Figure 34.47, the current as a function of potential difference and the stopping potential as a function of the frequency of the incident light.



The photons described in Section 34.5 are these quanta. When an electron absorbs a photon, the electron acquires the photon's entire energy—the electron cannot absorb just part of a photon. The photon's energy frees the electron from the material and gives it additional kinetic energy. If we denote the minimum energy required to free the electron by E_0 , we have

$$E_{\text{photon}} = hf = K_{\max} + E_0 \quad (34.35)$$

where K_{\max} is the maximum kinetic energy of the electron as it is ejected. The energy E_0 , called the **work function** of the target metal, is a property of the metal that measures how tightly electrons are bound to the metal.

$$E_{\text{photon}} = hf_{\text{photon}}$$

$$V_{stop} = \frac{h}{e}f - \frac{E_0}{e}, \quad p_{\text{photon}} = \frac{h}{\lambda_{\text{photon}}} = \frac{hf_{\text{photon}}}{c_0} = \frac{E_{\text{photon}}}{c_0}, \quad E^2 - (c_0 p)^2 = (mc_0^2)^2, \quad p_{\text{photon}} = \frac{hf_{\text{photon}}}{c_0}, \quad (\text{Bruv, it's just } E=hf \text{ justification/deriving})$$

-Maximum kinetic energy of electrons ejected depends on the light frequency. Higher freq = more K (E=hf).

-Higher amplitude shoots out more photons over time and so more electrons have a chance to eject.

- Instead of the classical predictions, what happens is different. (And this experiment has been done many different times in various ways... always with results that contradict the classical predictions.)
- For most visible light frequencies, there is no current produced, regardless of the intensity of the light.
- If there is a current, there is no time delay between when the light is turned on and when the current is measured.
- If there is a current, the current is proportional to the intensity of the light.
- The maximum energy of the electrons is proportional to the frequency of the light and is not affected by the intensity of the light.
- Different metals have a different cutoff frequency below which no current occurs, but all of them follow the same linear pattern above the cutoff frequency... with the same slope!

-In conclusion

- Light is treated as a photon "particle", that has frequency and acts like a wave too. Bruh moment be like
- So light does appear to be "packaged" in chunks of energy.
- We call the particles of light photons.
- Light can be modeled as a stream of photons where the energy of each photon is proportional to the frequency of that photon.
- But how can a single thing have a frequency?
- And how can these photons interfere with each other to produce single slit and double slit diffraction patterns like those we looked at previously?
- That is part of the mystery of light!
- But there's more!

-Photon momentum

$$p = \frac{h}{\lambda}$$

-Photon energy when it slows down

-Slow down photon wave speed such as travelling through different medium. Energy doesn't change. Energy depends on frequency.

What happens to the energy of a photon when its speed is reduced to half its initial speed (as, for instance, when the photon travels from a medium with an index of refraction of 1 into a medium with an index of refraction of 2)?

- The energy increases by a factor of 4.
- The energy reduces to 1/2 of its initial value.
- The energy reduces to 1/4 of its initial value.
- The energy increases by a factor of 2.
- The energy does not change.

[Check](#) [Previous Answers](#)

Correct

The energy of a photon depends only on its frequency and the frequency is fixed when a photon crosses from one medium to another. It is only the wavelength that changes.

-Work function of a metal (Values for dif metals: <http://hyperphysics.phy-astr.gsu.edu/hbase/Tablesp/photoelec.html>)

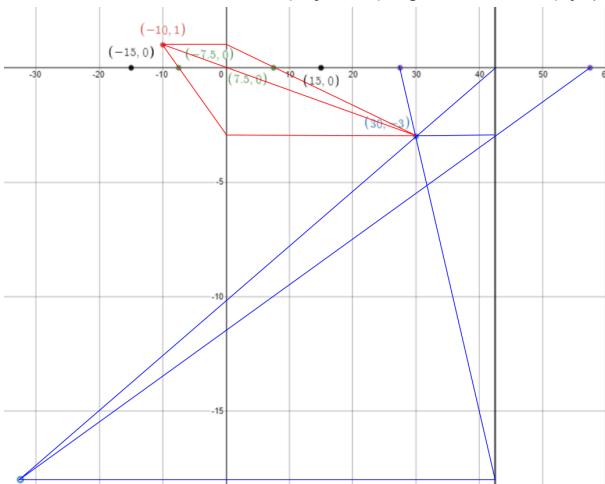
-The amount of energy required to remove free electrons from a metal. Note that this is not the same as ionization energy that you may have studied in chemistry. Ionization energy is about individual atoms. The work function comes from measurements on atoms that are bonded with other atoms in a metallic solid.

-Cutoff frequency for a metal

-the lowest possible frequency that will provide enough energy to release a free electron. In other words, it is the frequency of electromagnetic waves that have a minimum energy equal to the work function for that metal. Or, using the particle model, the frequency of a photon that has energy equal to the work function for that metal. The cutoff frequency corresponds to a cutoff wavelength, which is the longest wavelength electromagnetic wave that will cause an electron to be ejected from the metal.

ColLab 7

#4: Dual Lens, left lens is 1st (objective), right lens is 2nd (eyepiece/iMagObject). Blue solid is 1st i. Blue hole is 2nd i.



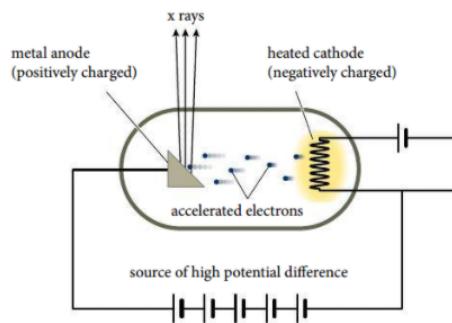
Mazur 34.3 X-ray diffraction

-X rays

-EM waves that have wavelength 0.01 nm to 10 nm.

-Xray emitter

Figure 34.14 Schematic diagram for a cathode ray tube x-ray emitter.



-Xray gets passes through soft tissues of human body, but get absorbed by bones and teeth, allowing for scans

-Xray also gets absorbed by heavy atoms.

-Since Xray have small enough wavelength, a solid atomic structure like crystal lattice cause diffraction

Figure 34.16 Two examples of crystal lattices.

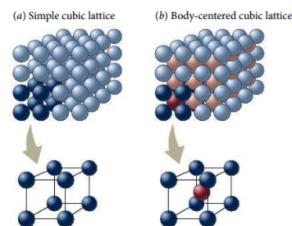


Figure 34.17 Diffraction of x rays by the atoms at the surface of a crystal lattice.

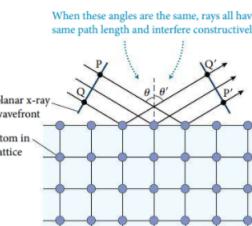


Figure 34.18 Interference of x rays diffracted by adjacent planes of a crystal.

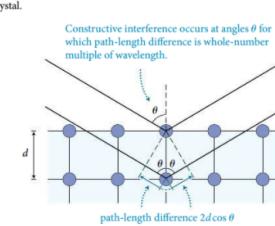


Figure 34.19 Constructive interference of x rays diffracted by two diagonal crystal planes.

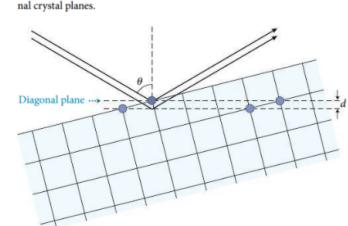
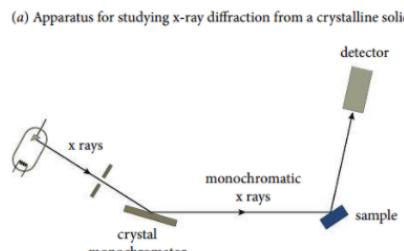


Figure 34.20 (a) Apparatus for studying x-ray diffraction from a crystalline solid. (b) Relationship between the incident angle θ and the Bragg angle α .



(b) Relationship between incident angle θ and Bragg angle α

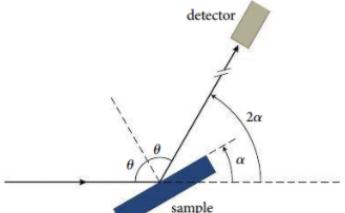
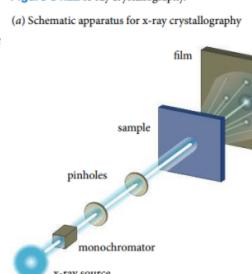
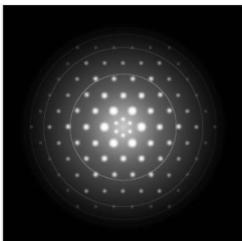


Figure 34.22 X-ray crystallography.



(b) X-ray diffraction pattern of diamond lattice



Mazur 34.4 Matter waves

-Electrons also get diffracted by the lattice crystal like Xray.

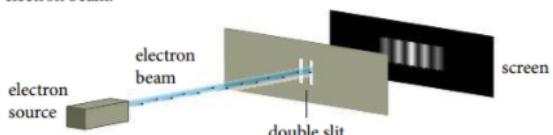
Figure 34.23 Electron diffraction pattern for a diamond lattice. Notice the similarity to the x-ray pattern in Figure 34.22b.



-Changing the speed of electrons launched shows a different diffraction pattern. Wavelength of electrons depends on speed.

-Electrons diffract like light through double slit

Figure 34.24 Apparatus for observing two-slit interference with an electron beam.



7.6 Particles as waves (ok dud)

-Atoms be like?

-Classical 5heads said atom is like earth around sun.

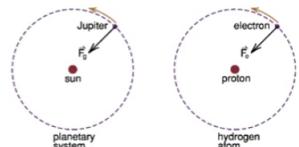


Figure 17-3
Classical picture of the hydrogen atom.

-But, if a charged particle accelerates, there are EM waves then! That means this model is poop because we haven't measured EM waves from sole atoms.

-Also, this model means that one day, the electron will fall into the proton because of the acceleration from circular motion.

-Also also, if it's an atom of protons only, why wouldn't they repel apart.

-Emission spectra

-Atoms do emit EM waves, just when specific conditions are met.

-Like when hydrogen gas glows with large electric potential through a tube.



-Different gas gives different colors (their condition to give EM waves are different too)

-Using a spectroscope (just a super duper cool diffraction grating), you can see the combo of EM waves that make up the final color.

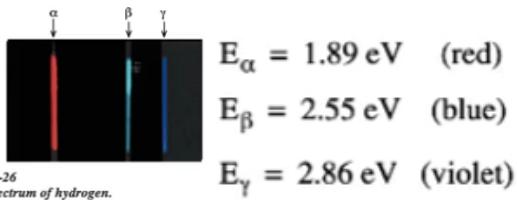
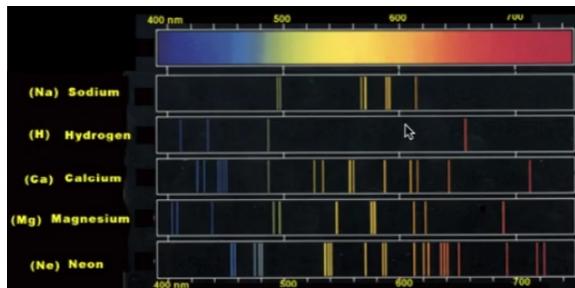


Figure 25-26
Visible spectrum of hydrogen.

(there are also Infrared & UV, but this doesn't show I guess)



-Where do these lines come from?

-Heads Neils Bohr find equation (Energy level of an electron)

$$E_n = -\frac{13.6}{n^2} \text{ eV}$$

$$E_{\text{photon}} (\text{in eV}) = \frac{hc}{\lambda} = \frac{1240 \text{ eV nm}}{\lambda (\text{in nm})} \quad (\text{n increments by integer}) \quad E_n = \frac{13.6 \text{ eV}}{n^2}$$

-Electrons can be in the En energy level. When they shift in between these En energy levels, they emit EM waves that have the same energy as the difference between En energy levels.

$$\begin{aligned} E_1 &= \frac{-13.6}{1^2} = -13.6 \text{ eV} & E_4 &= -0.85 \text{ eV} & E_3 - E_2 &= 1.89 \text{ eV} \\ E_2 &= \frac{-13.6}{2^2} = -3.40 \text{ eV} & E_5 &= -0.54 \text{ eV} & E_4 - E_2 &= 2.55 \text{ eV} \\ E_3 &= \frac{-13.6}{3^2} = -1.51 \text{ eV} & E_6 &= -0.38 \text{ eV} & E_5 - E_2 &= 2.86 \text{ eV} \end{aligned}$$

(These specific differences are the energy of hydrogen EM wave pattern)

-En levels drawn in circular or vertical diagram.

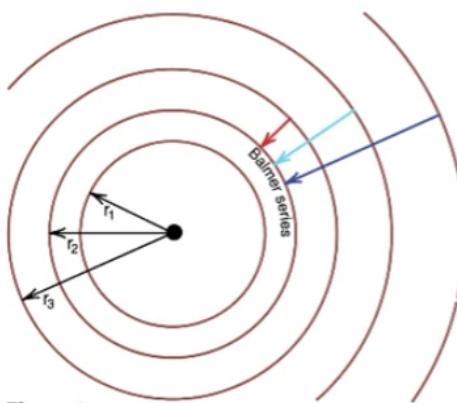
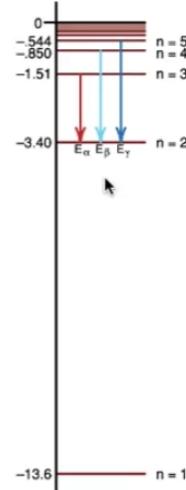


Figure 2
The Bohr orbits are determined by calculating the orbital radius of an electron in a circular classical orbit of energy $E_n = -13.6/n^2$.



(The arrow are the differences pattern for hydrogen)

-Bohr said electrons can't fall inward because each is at an energy level.

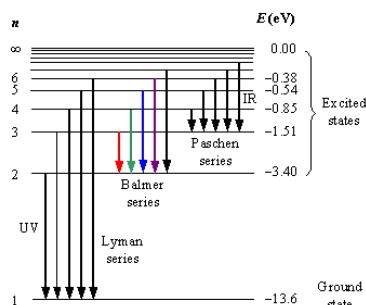
-He calculated that r_1 is 0.053 nm, the first electron away from the nucleus

-And the proceeding radius is (Mr Eller chemistry be like)

$$r_n = n^2 r_1$$

-UV, Visible, Infrared patterns/series

-UV transition to level 1, Visible to level 2, IR to level 3.



Energy levels of the hydrogen atom with some of the transitions between them that give rise to the spectral lines indicated

-Angular momentum of hydrogen

-Bohr also calculated

$$L_n = nL_1 \quad L = rp = rmv.$$

-Finding speed of electron at r_1 (Hydrogen's electron)

$$L_1 = r_1 p = r_1 m v_1.$$

We can use Bohr's value for r_1 , and we know the mass of an electron, but what is its speed?

- Anything going in circular motion must have a centripetal force $F_c = \frac{mv^2}{r}$.
- In this case, we are claiming that the centripetal force is the Coulomb force: $F_c = \frac{kq_1 q_2}{r^2}$.
- Both the proton and electron have the elementary charge e , so we have

$$\frac{mv^2}{r} = \frac{ke^2}{r^2} \text{ which yields } v = \sqrt{\frac{ke^2}{mr}}$$

$$L_1 = r_1 m v_1 = r_1 m \sqrt{\frac{ke^2}{r_1 m}} = \sqrt{ke^2 r_1 m}$$

- $k = 9.0 \times 10^9 \text{ N m}^2/\text{C}^2$
- $e = 1.6 \times 10^{-19} \text{ C}$
- $m = 9.11 \times 10^{-31} \text{ kg}$
- $r_1 = 5.3 \times 10^{-11} \text{ m}$

$$L_1 = 1.055 \times 10^{-34} \text{ J s}$$

It is Planck's constant divided by 2π !

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

$$L_n = nL_1 = n\hbar$$

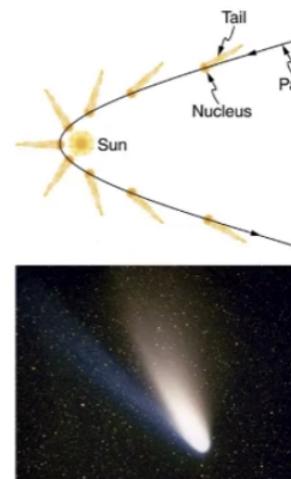
-This only works for hydrogen, but it's still cool

-Photon momentum

Photon momentum

- Maxwell's equations suggested that electromagnetic waves carried momentum as well as energy.
- In Einstein's 1905 paper on special relativity, he presented a relationship between energy and momentum that can be written as $E^2 = p^2 c^2 + m_0^2 c^4$, where m_0 is the object's rest mass.
- (If the object is not moving, this reduces to the famous equation $E = mc^2$.)
- Photons were assumed to have zero rest mass, so that leaves $E = pc$.
- But we already have Planck's proposal that $E = hf$, so we can write the momentum of a photon as

$$p = \frac{E}{c} = \frac{hf}{c} = \frac{hc}{c\lambda} = \frac{h}{\lambda}$$



-So does everything that has momentum have a wavelength?

-Electron wavelength (Broglie Momentum & Wavelength relationship)

-Standing waves on a ring related to an electron's wavelength.

Electrons as standing waves

- Recall that the Bohr model was introduced in 1913.
- In 1924, a graduate student in France, Louis de Broglie, submitted his Ph.D. dissertation. In it, he proposed that an electron has a wavelength that depends on its momentum in the same way as a photon:

$$p = \frac{h}{\lambda}$$

- As we just saw, this formula came from an assumption that photons have zero rest mass, and electrons do not have zero rest mass, so this was not an obvious proposal.

$$\text{But De Broglie used the wavelength } \lambda = \frac{h}{p}$$

to explain Bohr's energy levels.

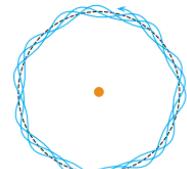
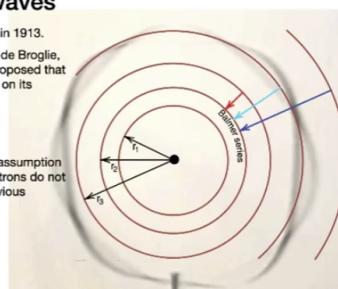


Figure 1
de Broglie picture of an electron wave cancelling itself out.

Figure 2
If the circumference of the orbit is an integer number of wavelengths, the electron wave will go around without any cancellation.

Electrons as standing waves

So the proposal is that the electron wavelength is $\lambda = \frac{h}{p}$

- If an integer number of the electron's wavelengths fit into the circumference of the electron's orbit, it would create a standing wave—constructively interfering with itself.
- Non-integer numbers of wavelengths would destructively interfere.
- So if integer wavelengths fit in the circle of radius r_n , we have $2\pi r_n = n\lambda = n\frac{h}{p_n}$.
- We can rewrite this as angular momentum:

$$L_n = r_n p_n = n\frac{h}{2\pi} = n\hbar$$

So if we assume electrons have wave properties, we find that we can predict that the angular momentum of electrons orbiting the nucleus will be quantized.

This quantization also implies quantization of energy states for the electron.

Not only does De Broglie's hypothesis work for hydrogen, it is the basis for the quantum approach that can be used to explain all the spectra of all the elements.

Experimental evidence supporting this was found in the backscattering of electrons from metallic crystals. These experiments in 1925 were the result of a malfunction, but the results were verified and linked to De Broglie's hypothesis in 1927.

Essentially, the experiment showed that electrons demonstrated diffraction and interference effects similar to those seen in light.

Since electron wavelengths are so small, the only way to get "slits" small enough to cause diffraction effects are the atomic lattices of crystalline structures.

-Matter Waves

-So does everything that has momentum have a wavelength?

-Quantum physics theory moon nowaday: yes.

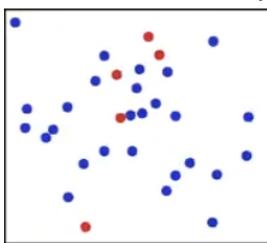
-Photon kinetic energy and momentum

$$K = \frac{1}{2} mv^2 = \frac{p^2}{2m} \rightarrow p = \sqrt{2mk} \quad K = \frac{1}{2} mv^2 \rightarrow v = \sqrt{\frac{2K}{m}} \text{ or } \frac{v}{c} = \sqrt{\frac{2K}{mc^2}}$$

8.2 Ideal Gas Law

-Ideal gas

- Particle collisions are totally elastic, no loss in kinetic energy.



-Micro Scale

- Mass of each particle
- Velocity of each particle
- Number of particles

-Macro Scale

- Mass of gas
- Volume
- Pressure
- Temperature

-Relating Micro and Macro scale

- Pressure is the avg forces of collision on the wall
- Temp is avg K energy of particles

-Ideal Gas Law

It gives the relationship among pressure, volume, temperature, and the number of particles of the gas:

$$PV = nRT \quad \text{or, equivalently,} \quad PV = Nk_B T$$

- P , V , and T are pressure, volume, and temperature
- n is the number of moles of the gas (which is a way of counting the particles)
- N is the actual number of particles of the gas
- R is the gas constant which has a value of 8.314 J/K per mole
- k_B is Boltzmann's constant (1.38×10^{-23} J/K)
- and $R = N_A k_B$ where N_A is Avogadro's number, 6.02×10^{23} (Pa, m³, mol, J/K, K)

-Energy of ideal gas

- Micro scale K energy relates to macro temperature

-The macro scale can be thought of as Internal Energy of the gas

-Because we suck, we are only considering gas that's not moving, so no macro velocity and gravity.

-Internal energy is then just the temperature of the gas.

-This is thermal energy, proportional to temperature of gas

-Converting from Temp (K) to Joules or reversed.

$$E_{th} = \frac{3}{2} Nk_B T \quad \text{or} \quad E_{th} = \frac{3}{2} nRT \quad (\text{monatomic gas})$$

or, more generally

$$E_{th} = \frac{d}{2} Nk_B T \quad \text{or} \quad E_{th} = \frac{d}{2} nRT \quad \text{where } d=3 \text{ for monatomic gases, } d=5 \text{ for diatomic gases, and more.}$$

The main point here is that if you know how much of a gas you have (either its mass, number of moles, or number of particles) and two other quantities from the list of P , V , T , and E_{th} , you can calculate the other two.

-Entropy

- Another macro property, the disorder of a system

-2nd law of thermodynamics: Entropy can only increase (or stay the same).

- But what is entropy really?
- It's really just a count... a count of all the ways a system could possibly be arranged.
- So we're going to need to learn to count arrangements or "basic states" so that we can understand Mazur's formulation of the Second Law of Thermodynamics, which he states on page 512 of the *Principles* text:

A closed system always evolves so as to maximize the number of basic states Ω . When this number has reached a maximum, the system is at equilibrium.

Again, for Mazur, entropy will be unitless and will generally be a very large number for any realistic situation that isn't at the atomic level. Whereas in the traditional approach, entropy will be a rather normal looking number with units of J/K... joules per kelvin.

The conversion between the two definitions is Boltzman's constant $k_B = 1.38 \times 10^{-23}$ J/K. You will use this constant a lot in thermodynamics.

-Entropy is an extensive property. Cutting an object in half will halve its entropy.

-As volume increases, so does the max number of basic states.

Essentially, the volume dependence of entropy is given by the permutation $\Omega = M^N$ (equation 19.1) so that the entropy can be written as

$$\text{for Mazur: } S = \ln(M^N) = N \ln M$$

$$\text{or for everyone else: } S = k_B \ln(M^N) = Nk_B \ln M.$$

But what is M? It is the number of subdivisions used in your counting process, and it is proportional to the volume of the gas. So we have

$$\text{for Mazur: } S = N \ln(cV) = N \ln V + N \ln c = N \ln V + \text{constant}$$

$$\text{or for everyone else: } S = Nk_B \ln V + \text{constant}$$

The constant will cancel out when we calculate changes in entropy, so we usually simply treat the constant as zero.

-Entropy increases due to volume (so every other property is the same):

If we don't change the number of particles (or the mass of the gas), we can calculate the change in entropy due to changes in volume quite simply:

$$\text{for Mazur: } \Delta S = N \ln V_f - N \ln V_i = N \ln\left(\frac{V_f}{V_i}\right)$$

$$\text{or for everyone else: } \Delta S = Nk_B \ln V_f - Nk_B \ln V_i = Nk_B \ln\left(\frac{V_f}{V_i}\right)$$

Here is where we find a mathematically satisfactory formula for entropy since the units for volume will cancel out before the logarithm is taken.

But this is not all of the entropy! Energy also contributes to entropy, so we need to find a way to work with temperature and entropy.

-Entropy and Temp

- Temperature is proportional to the average kinetic energy of the particles in an ideal gas. If the particles of a gas are monatomic (one atom per particle), this proportionality can be written as given in equation 19.52:

$$K_{avg} = \frac{3}{2}k_B T$$

- Another way to define entropy is to say that the change in entropy is the change in thermal energy divided by absolute temperature: $\Delta S = \frac{\Delta E_{th}}{T} = \frac{Q}{T}$, where Q is the symbol usually used for heat transfer. This is why entropy has units of joules per kelvin for everyone other than Mazur. Mazur turns this around and uses it to define absolute temperature in equation 19.38: $\frac{1}{k_B T} = \frac{dS}{dE_{th}}$. Notice that he has to include the Boltzmann constant in this formula to fix his definition of unitless entropy.

- If volume is held constant, the entropy of a monatomic ideal gas changes according to equation 19.56 (using Mazur's unitless entropy): $\Delta S = \frac{3}{2}N \ln(T_f) - \frac{3}{2}N \ln(T_i) = \frac{3}{2}N \ln\left(\frac{T_f}{T_i}\right)$.

$$\text{This would again change for everyone besides Mazur to be } \Delta S = \frac{3}{2}Nk_B \ln\left(\frac{T_f}{T_i}\right).$$

-Entropy by Temp and Volume (just add them 4head)

$$\text{for Mazur: } \Delta S = \frac{3}{2}N \ln\left(\frac{T_f}{T_i}\right) + N \ln\left(\frac{V_f}{V_i}\right)$$

$$\text{for everyone else: } \Delta S = \frac{3}{2}Nk_B \ln\left(\frac{T_f}{T_i}\right) + Nk_B \ln\left(\frac{V_f}{V_i}\right)$$

8.7 Heat, temperature, and work

-Heat is the process of energy transfer.

-Energy transfer goes from high temp to low temp.

-Energy is conserved, no new energy comes from heat.

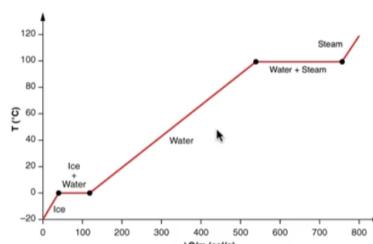
-Temp change can happen without heat transfer

-Stirring liquid increases temp.

-This is an example of work, meaning work can increase temp.

-Heat transfer doesn't always affect temp

-Phase change requires heat transfer, but the temp of the material undergoing heat transfer can still be the same.



(The horizontal part is where heat transfer is still going on but temp doesn't change)

-Also, we can apply heat transfer while changing the pressure and/or volume just right to counteract the heat transfer temp affect and keep temp the same.

-Heat Capacity

-Same graph as above.

-Since it's linear, there is a linear relationship between heat transfer and temp.

- Q is heat transfer, C is heat capacity

- Other than during phase change, the change in temperature is proportional to heat transfer
- The constant of proportionality is different in solid than in liquid and different again for the gas phase.
- The constant is called "heat capacity" and is usually given the symbol C .

$$Q = C \Delta T$$

$$\text{or } q = c \Delta T \text{ on a per unit mass basis } Q = mc \Delta T$$

- For example, 1 calorie or 4.18 J is enough energy to raise the temperature of 1 gram of liquid water by 1 °C or 1K.
- Lead, on the other hand, only requires 0.129 J of energy per gram to change by 1 °C.

Table 20.2 Specific heat capacities

Material	c (J/K · kg)
alcohol	2436
aluminum	897
brass	385
carbon graphite	685
copper	385
glass	837
gold	130
helium	3116
ice (268 K)	2090
iron	449
lead	130
marble	860
mercury	140
nickel	443
platinum	133
silver	235
steam (373 K)	1556
titanium	527
water	4181
wood	1700
zinc	388

Table 20.3 Heat capacities per particle in units of k_B

Class	Material	C_V/k_B
Monatomic gases	helium	1.50
	argon	1.50
	krypton	1.50
	xenon	1.51
	radon	1.51
Polyatomic gases	ammonia	3.37
	hydrogen	2.47
	nitrogen	2.50
Liquids	mercury	3.38
	water	8.97
Solids	aluminum	2.91
	copper	2.94
	gold	3.08
	iron	3.02
	silver	3.05
	titanium	3.04
	zinc	3.05

All values are reported at a temperature of 298 K (unless otherwise noted) and atmospheric pressure and with the gases held at constant volume.

All values are reported at a temperature of 298 K and atmospheric pressure and with gases held at constant volume (as indicated by the subscript V on C_V).

-Heating gases

-When gas is heat, the resulting heat capacity depends on if P or V is allowed to change.

- If volume is held constant, the pressure of the gas will increase, and we can write $Q = C_V \Delta T$, where C_V is the "constant volume" heat capacity of the gas.
- If pressure is held constant, the volume of the gas will increase, and we can write $Q = C_P \Delta T$, where C_P is the "constant pressure" heat capacity of the gas.
- Note that Mazur defines heat capacity per particle, so his formulas are $Q = N C_V \Delta T$ and $Q = N C_P \Delta T$.
- If we can approximate the gas as an ideal gas, the pressure, volume, and temperature will all be related by $PV = nRT$ (or $PV = Nk_B T$).

-Since thermal energy is the only energy (because we suck and simple is cool)

- If we have an ideal gas that has no center of mass motion and no potential energy change (no change in altitude; no chemical reactions occurring), the only way its energy can change is thermally:

$$\Delta E = \Delta E_{th}$$

- This means that, to within a constant, the total energy of the system is the same as its thermal energy:

$$E_{total} = E_{th} + \text{constant}$$

- In chapter 19, we worked out that the thermal energy could be written in terms of temperature: $E_{th} = \frac{3}{2} N k_B T$.

- We are now going to change this slightly: $E_{th} = \frac{d}{2} N k_B T$, where d is the degrees of freedom of the molecules in the gas. More on this later....

-Work of piston on gas

WORK

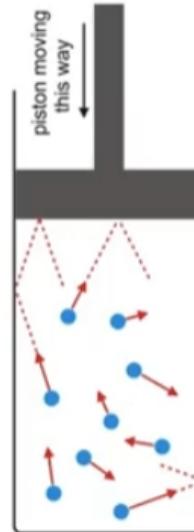
- But we have seen that we can also increase the temperature (and thus the thermal energy) of a gas by doing work on it.
- For example, we could compress the gas.
- How much work is done? We can use the definition of work

$$W = \int \vec{F} \cdot d\vec{x}$$

- If the piston and container are frictionless, the force required to move the piston is due to the pressure of the gas inside the container: $F = PA$.
- Multiplying the area times dx is the magnitude of the change in volume, but notice that increasing dx is causing a decrease in volume, so we have $A dx = -dV$. Substituting this in the formula above gives

$$W = \int \vec{F} \cdot d\vec{x} = \int P A dx = - \int P dV$$

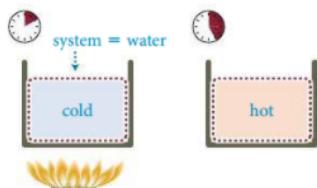
- It may be necessary to do this as an integral since the pressure could change in the process, but there is a special case where P remains constant as the gas is compressed. Then, the integral becomes just $W = -P \Delta V$.



Mazur 20.1 Thermal interactions

Figure 20.2 When a pot of water is heated, the energy diagram for a system comprising only the water is unbalanced.

(a) Initial and final states



(b) Energy diagram for system

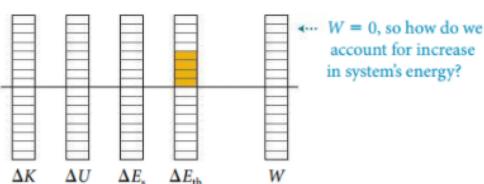


Figure 20.3 To complete the energy diagram of Figure 20.2, we must add a bar to account for the energy transferred thermally into the system (represented by the symbol Q).

Bar accounts for energy transferred thermally to system.

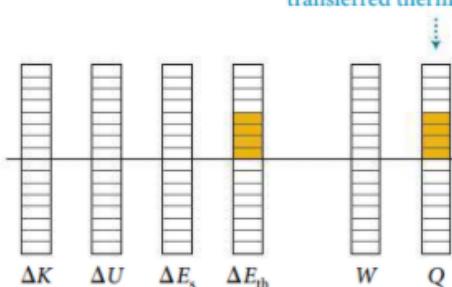


Figure 20.4 When gases of different temperatures are placed in thermal contact, energy is transferred thermally from the hotter to the cooler gas until the temperatures of the two gases are the same.

(a) Gases at different temperatures are placed in thermal contact

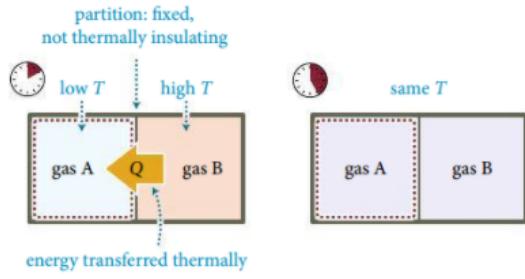
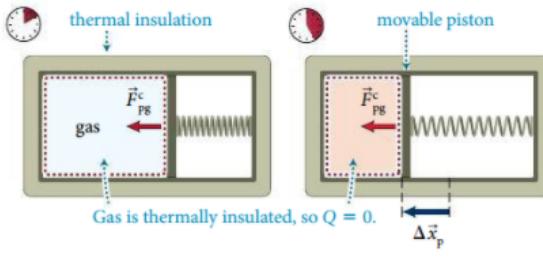


Figure 20.5 A piston does work on a thermally insulated ideal gas, increasing the gas's temperature.

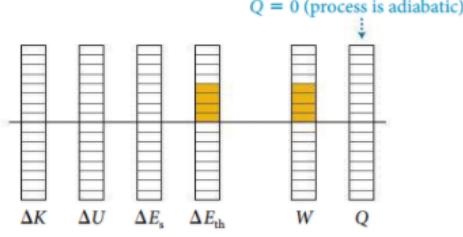
(a) Spring-loaded piston compresses thermally insulated ideal gas



(b) Energy diagram for gas A



(b) Energy diagram for gas



$$\Delta E = W + Q$$

(Its delta E_{th} here, because ideal gas only considers thermal energy)

Work VS Heat Transfer

Transferring energy to a system

DOING WORK	TRANSFERRING ENERGY THERMALLY
Technical term:	Mechanical interaction between system and its environment
Mediated by:	Thermal interaction between system and its environment
Requires:	Macroscopic pushes and pulls
Amount of energy transferred <i>into</i> system:	Atomic collisions
Sign:	A nonzero temperature difference ΔT between the system and its environment.
Equilibrium:	A nonzero external force \vec{F}_{ext} exerted on the system and a nonzero force displacement $\Delta \vec{x}_F$
W ("work done on system")	Q ("energy transferred thermally to system")
$W > 0$ when external force and force displacement are in the same direction (energy of system increases in absence of other transfers)	$Q > 0$ when environment is at a higher temperature than system (energy of system increases in absence of other transfers)
$W < 0$ when external force and force displacement are in opposite directions (energy of system decreases in absence of other transfers)	$Q < 0$ when environment is at a lower temperature than system (energy of system decreases in absence of other transfers)
The vector sum of the external forces is zero, and the force displacement of each external force is zero (mechanical equilibrium)	System is at same temperature as its environment (thermal equilibrium)

-Entropy decreases!

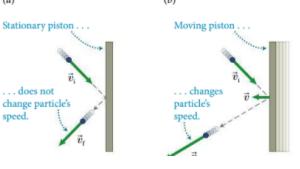
Transferring energy thermally to a system increases its entropy. Transferring energy thermally from a system decreases its entropy.

-Temp chat war

Table 20.1 Comparison of temperature scales (defining points in bold)

Temperature	Kelvin (K)	Celsius (°C)	Fahrenheit (°F)
Absolute zero	0	-273.15	-459.67
Water freezes (at a pressure of 101.325 kPa)	273.15	0	32
Triple point of water	273.16	0.01	32
Room temperature	293	20	68
Average human body temperature	310	37.0	98.6
Water boils (at a pressure of 101.325 kPa)	373.12	100	212
Titanium melts	1941	1668	3034
Surface of the Sun	5778	5505	9941

Figure 20.6 A stationary piston does not change the speed of a gas particle that collides with it, but a moving piston does.



Process	Properties Held Constant
Adiabatic	Heat Energy
Isenthalpic	Enthalpy
Isentropic	Entropy, Equilibrium, Heat Energy
Isobaric	Pressure
Isochoric	Volume
Isothermal	Temperature
Isotropic	Direction
Polytropic	$PV^n = C$
Reversible	Entropy, Equilibrium

-Ex

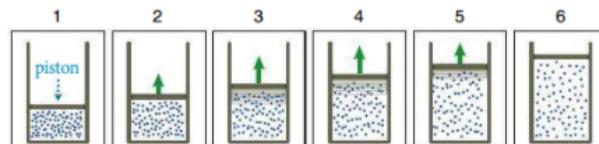
An ideal gas expands adiabatically and quasistatically in a chamber fitted with a piston.

This is isentropic since both P & V are changing, still maintaining equilibrium because ada & quasi.

-Also, there's Quasistatic & Non-Quasistatic compression & expansion (The processes starred use Quasistatic)

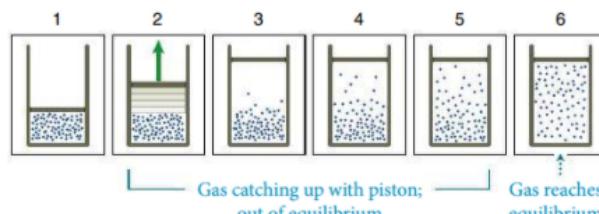
Figure 20.7 Quasistatic versus non-quasistatic expansion of a cylinder containing a gas.

(a) Quasistatic expansion: piston rises gradually



At all instants, gas fills container uniformly (is in equilibrium).

(b) Non-quasistatic expansion: piston rises suddenly



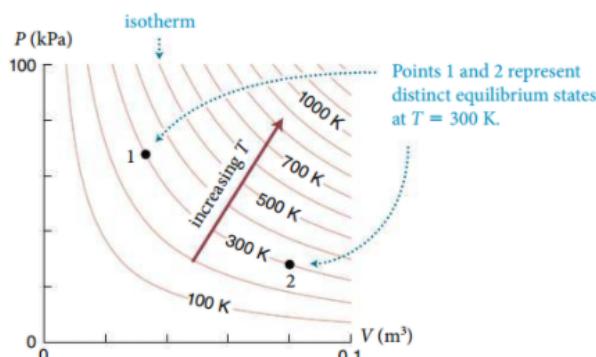
Mazur 20.4 PV (Pressure and Volume) Diagrams/Graphs and Processes

-So like, gas wants to reach equilibrium in P vs V. These are the lines of equilibrium in which the P&V equilibrium increases as temp increases.

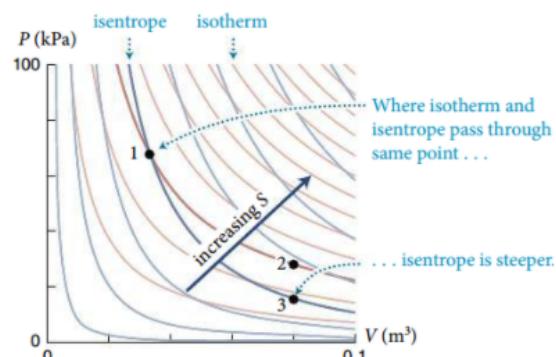
Any point on a PV diagram represents an equilibrium state in which the gas has a well-defined temperature, thermal energy, and entropy.

Figure 20.20 Isotherms and isentropes in a PV diagram for an ideal gas. Points 1 and 2 represent two equilibrium states, both at $T = 300\text{ K}$. In general, on a PV diagram, the isentrope passing through a given point is steeper than the isotherm passing through that point.

(a) PV diagram showing isotherms (curves of constant temperature T) for an ideal gas



(b) Isentropes (curves of constant entropy S) superimposed on isotherms



Isentropic process

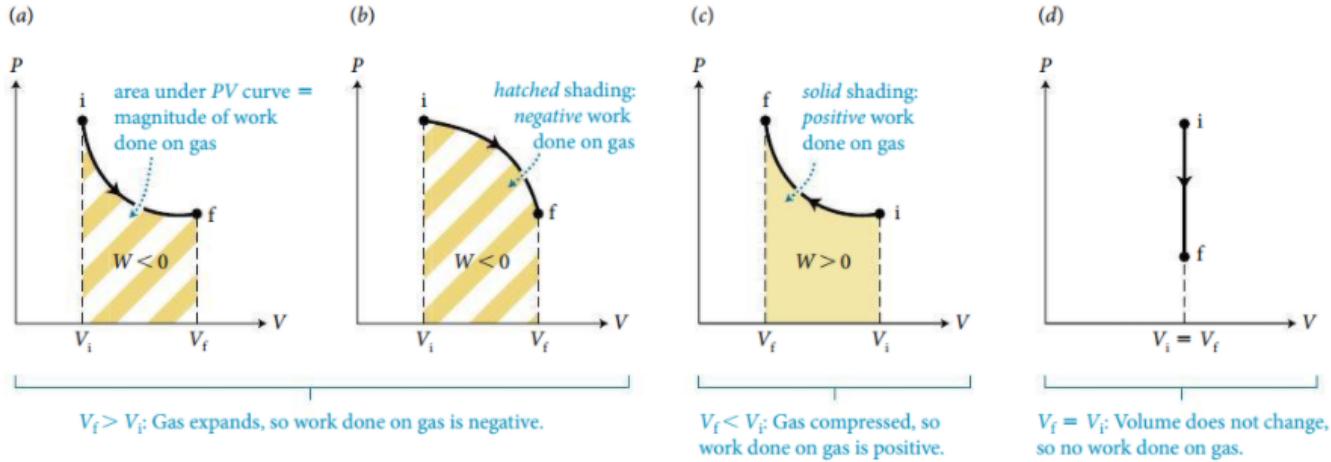
In thermodynamics, an isentropic process is an idealized thermodynamic process that is both adiabatic and reversible. The work transfers of the system are frictionless, and there is no net transfer of heat or matter. [Wikipedia](#)

During a quasistatic process, the system remains near equilibrium at all instants. Such a process can be represented by a continuous path on a PV diagram.

When an ideal gas is transformed from one equilibrium state to another, the changes in the thermal energy and entropy of the gas are independent of the process.

-PV graphs and work

Figure 20.23 The work done on a gas during a quasistatic process is equal to the area under the path on the PV diagram representing that process.



$$W = - \int_{V_i}^{V_f} P(V) dV \quad (\text{or}) \quad W = - \int_{V_i}^{V_f} \Delta P dV$$

(negative sign is for convention)

-Types of quasistatic processes in PV graph

Figure 20.25 Four types of constrained quasistatic processes.

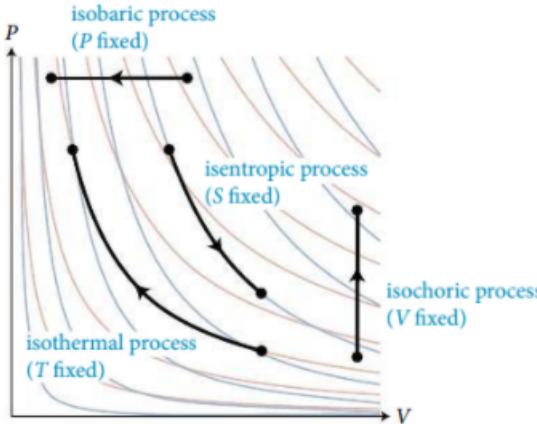


Table 20.5 Constrained quasistatic processes

Process	Constraint	Consequence
isochoric	V fixed	$W = 0$
isentropic (adiabatic)	S fixed	$Q = 0$.
isobaric	P fixed	
isothermal	T fixed	$\Delta E_{\text{th}} = 0$

9.2 Heat transfer, work, and entropy

-ok, energy can be changed by work and heat transfer. Or, it's thermal energy change

$$\Delta E = W + Q \quad \Delta E = \Delta E_{\text{th}} = W + Q = \frac{d}{2} N k_B \Delta T$$

-State of an ideal gas

-We can combine all them equations

- The ideal gas law shows us that if we know the pressure and volume and amount of an ideal gas, we also know its temperature.

(The “amount” can either be the number of particles or the number of moles or the mass, all of which can be converted among each other for a particular gas.)

- If we know the temperature, we know the thermal energy of the gas.
- And because entropy is a function of only temperature and volume, we also know the entropy of the gas
- All of these things are “state” variables: P , V , T , E , S
- When a gas is in a particular “state” all of these are known.
- Moving from one state to another may change these quantities, but the change depends only on the initial and final states:

$$\Delta P, \Delta V, \Delta T, \Delta E, \Delta S$$

$$PV = nRT$$

$$PV = Nk_B T$$

$$E = \frac{d}{2} nRT$$

$$E = \frac{d}{2} Nk_B T$$

$$S = N \ln(T^{\frac{d}{2}} V)$$

$$S = Nk_B \ln(T^{\frac{d}{2}} V)$$

-Quasistatic Processes

- The first limitation we will place on processes that change gases is that they be what is called "quasistatic".
- This is almost an oxymoron. It means we are going to change the state of the gas so slowly that it's almost as if it didn't change, and it could very easily go back to its previous state.
- No processes that accomplish macroscopic change are truly quasistatic, but we can approximate processes as quasistatic and treat that as the limit.
- If the gas is also insulated so that there is no heat transfer ($Q = 0$), then this is called an adiabatic process, and it will have no entropy change during the process, so it is an isentropic process.

-Quasistatic + Adiabatic = Isentropic

-Isothermal

-Temp constant

$$\Delta E = 0 = W + Q \quad \& \quad Q = -W$$

-So work & heat transfer is

Using the definition of work:

$$W = - \int P dV = - \int \frac{nRT}{V} dV = -nRT \int \frac{dV}{V} = -nRT(\ln(V_f) - \ln(V_i)) = -nRT \ln\left(\frac{V_f}{V_i}\right)$$

And that means that the heat transfer must be

$$Q = nRT \ln\left(\frac{V_f}{V_i}\right)$$

-Isentropic

-Heat transfer is zero

-That means $\Delta E = W + Q = W + 0 = W$

$$Q = 0, \text{ then } \Delta E = W + Q = W + 0 = W$$

-Work and Heat capacity

So the work done on the gas must be equal to the change in the thermal energy of the gas:

$$W = \frac{d}{2} N k_B \Delta T$$

Using the definition of heat capacity at constant volume, this can be rewritten as

$$\Delta E = W = N C_V \Delta T : m C_V \Delta T$$

\uparrow
 J
 $K \cdot kg$

-Change in entropy

Changes in entropy are due to changes in energy or volume. Since the only energy we are considering is thermal energy, this means that entropy changes can be calculated from temperature and volume:

$$\Delta S = \frac{d}{2} N k_B \ln\left(\frac{T_f}{T_i}\right) + N k_B \ln\left(\frac{V_f}{V_i}\right)$$

Using the rules for logarithms, this can also be written as

$$\Delta S = N k_B \ln\left(\left(\frac{T_f}{T_i}\right)^{\frac{d}{2}} \left(\frac{V_f}{V_i}\right)\right)$$

-If isothermal

Because the temperature does not change, you can see that

$$\Delta S = \frac{d}{2} N k_B \ln\left(\frac{T_f}{T_i}\right) + N k_B \ln\left(\frac{V_f}{V_i}\right) = N k_B \ln\left(\frac{V_f}{V_i}\right)$$

But we also know that

$$Q = -W = \int P dV = \int \frac{N k_B T}{V} dV = N k_B T \int \frac{dV}{V} = N k_B T \ln\left(\frac{V_f}{V_i}\right)$$

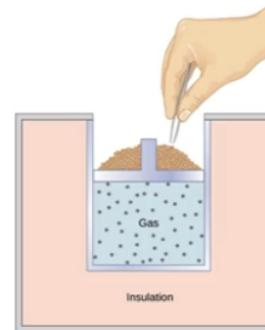
So we have that

$$\Delta S = \frac{Q}{T} \quad \text{or, for Mazur,} \quad \Delta S = \frac{Q}{k_B T} \quad \text{This is true even for non ideal gases.}$$

$$W = T \Delta S$$

9.6 Heat engines

-Heat Engine





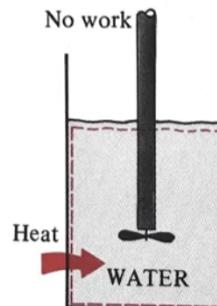
- Application of heat transfer
- Conservation of energy
- Putting heat to work
- Constraints due to entropy
- Efficiency

-What if we used heat to do work?

-Ex: Heating the water will not cause the paddle to spin.

So we can use heat to do work, but there are constraints.

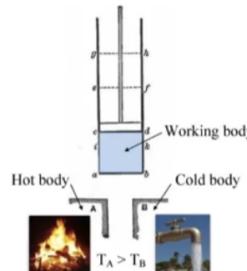
- This picture won't work because it has only one heat transfer process and it is taking heat out of the environment.
- Work done on the environment does not change the entropy of the environment.
- That means the entropy change of the environment would be negative.
- If any of the heating of the water was transformed into work instead of temperature change, the entropy increase of the water would be less than the entropy change of the environment.
- According to the 2nd law, this can't happen.
- And this process isn't cyclical, so the water would have to be able to keep heating up!



-Steady device

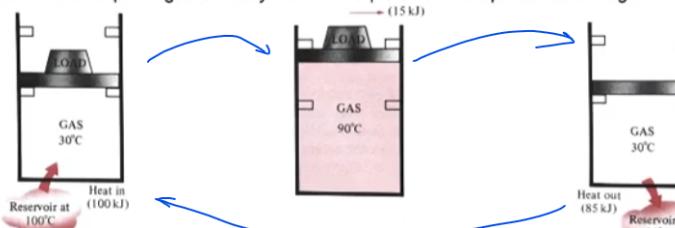
Cycles, steady devices, and reversibility

- While we have this example in mind, let's be a little more specific about the design of a useful device.
- To make something that can do the same job over and over, we need to design it to work in a cycle... it needs to return to its starting conditions.
- In a steady device, the energy and entropy of the device are the same when it returns to the same point in its cycle.
- Such a device is also internally reversible.
- If the environment is also unaltered after the completion of the cycle (that is, if the energy and entropy of the environment have not changed), then the process is fully reversible.
- Fully reversible processes are only an ideal. In reality, there is always something that makes a process irreversible: friction, unrestrained expansion, or heat transfer through a non-infinitesimal temperature difference.



-Ex: Environment Entropy Change

Consider this example. A gas is in a cylinder with a piston at the top that has a weight on top of it.



First, let's heat the gas.

This will cause the gas to expand, lifting the weight.

Take the weight off and cool the gas.

- The volume of the gas will decrease.
- When the piston gets down to the bottom, put on another weight and start over.

- But also notice that the process requires two thermal reservoirs at different temperatures.
- What happens to the energy of the environment?
- What happens to the entropy of the environment?

- We are focused on the total entropy change of the environment, which occurs in two stages. Heat is transferred out of the environment through the high-temperature reservoir, decreasing the entropy of the environment: $\Delta S_H = \frac{-Q_H}{T_H}$

- The low-temperature reservoir receives a heat transfer which increases the entropy of the environment: $\Delta S_L = \frac{Q_L}{T_L}$

- The total entropy change of the environment will be the sum of these two:

$$\Delta S_{env} = \frac{-Q_H}{T_H} + \frac{Q_L}{T_L}$$

- For this process to be possible, the entropy change of the environment must be greater than or equal to zero.

$$\Delta S_{\text{env}} = -(Q_{\text{in}} - Q_{\text{out}}) \left[\frac{1}{k_B T_{\text{in}}} \right] + Q_{\text{out}} \left[\frac{1}{k_B T_{\text{out}}} - \frac{1}{k_B T_{\text{in}}} \right]$$

$$\Delta S_{\text{env}} = -\frac{Q_{\text{in}}}{k_B T_{\text{in}}} + \frac{Q_{\text{out}}}{k_B T_{\text{out}}} \quad (\text{complete cycle}),$$

(Mazur uses $k_B = 1.38064852 \times 10^{-23}$)

$$\begin{aligned} \Delta S &= \Delta S_1 + \Delta S_2 \\ &= \frac{Q_{\text{out}}}{k_B T_{\text{out}}} - \frac{Q_{\text{out}}}{k_B T_{\text{in}}} \end{aligned}$$

(If only given thermal energy transferred in aka Q_{out} (idk why it's not Q_{in} but ok))

How does it work in this example?

$$\Delta S_{\text{env}} = \frac{-100 \text{ kJ}}{373 \text{ K}} + \frac{85 \text{ kJ}}{293 \text{ K}} = -0.268 \text{ kJ/K} + 0.29 \text{ kJ/K} = 0.022 \text{ kJ/K}$$

-This example is Bottom Gear Petrol Head Combustion Heat Engine

-Summary of Entropy change

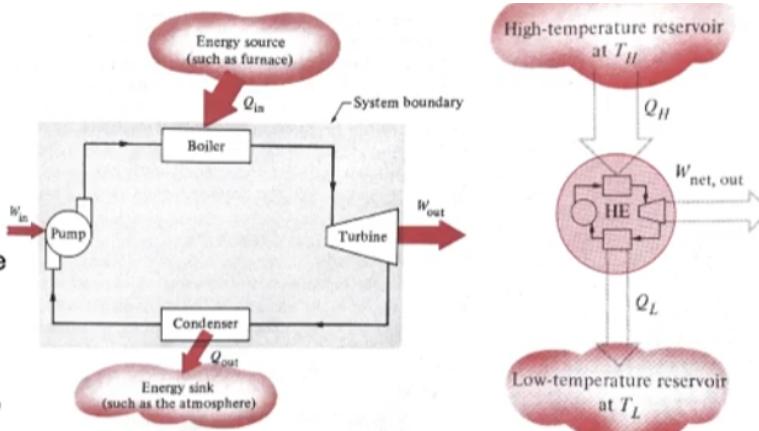
$$\begin{aligned} \Delta S_{\text{subs tan c}} &= \frac{Q_{\text{subs tan c}}}{T_{\text{subs tan c}}} \\ \Delta S_{\text{env}} &= \frac{Q_{\text{env}}}{T_{\text{env}}} \\ \Delta S &= \Delta S_{\text{subs tan c}} + \Delta S_{\text{env}} \end{aligned}$$

(If heat is leaving, negative. Temp is always Kelvin)

-Heat Engine

-High temp is turned into work and low temp waste.

- This is also the structure of external combustion engines that are used to produce electricity.
- In general, heat engines produce work, but they require two heat reservoirs.
- This means that you cannot turn heat completely into work, though you can turn work completely into heat.



-Efficiency

- For a heat engine, this becomes

$$\eta = \frac{W_{\text{net, out}}}{Q_H}$$

$$\eta \equiv \frac{-W}{Q_{\text{in}}}.$$

- Notice that since $Q_H = W_{\text{out}} + Q_L$, we have that $W_{\text{out}} = Q_H - Q_L$ so another way to write the efficiency of a heat engine is

$$\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

$$\eta = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}} = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}}$$

(Q can be replaced with T as well)

-Heat Pump

-Coefficient of performance of heating

$$\text{COP}_{\text{heating}} = \frac{Q_{\text{out}}}{W}$$

-Coefficient of performance of cooling

$$\text{COP}_{\text{cooling}} = \frac{Q_{\text{in}}}{W}$$

-Change in Thermal Energy

$$\Delta E_{\text{th}} = 0 = (Q_H - Q_L) + W$$

-Work done on the environment (negative to work on gas)

$$W_{\text{out}} = -W = Q_H - Q_L$$

Mazur 21.1 Converting Energy

-Mechanical energy

$$W = W_{\text{in}} - W_{\text{out}}$$

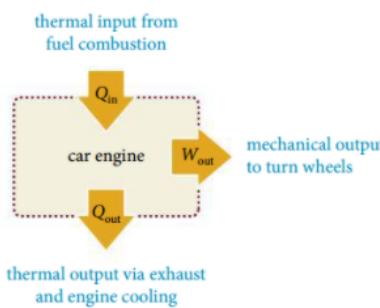
-Thermal energy

$$Q = Q_{\text{in}} - Q_{\text{out}}$$

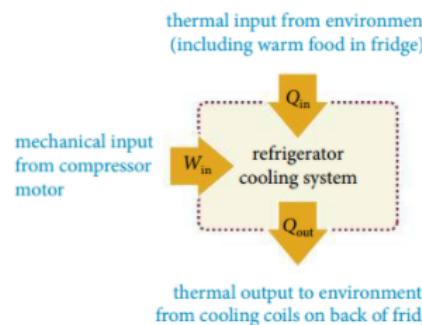
-Example Energy in/out diagrams

Figure 21.2 Examples of energy input-output diagrams.

(a) Energy input-output diagram for car engine

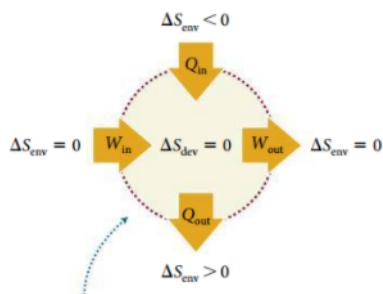


(b) Energy input-output diagram for refrigerator



-Steady device

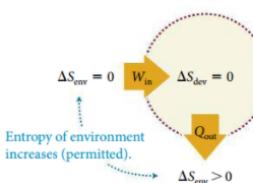
Figure 21.7 Energy and entropy changes associated with energy inputs and energy outputs for a steady device.



Circular system boundary indicates steady device ($\Delta E = 0, \Delta S_{\text{dev}} = 0$).

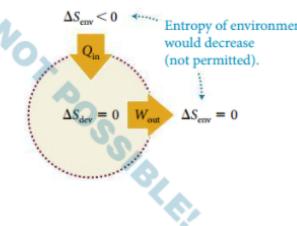
Figure 21.8 Energy input-output diagrams for two types of steady device.

(a) Device that converts mechanical energy to thermal energy



Steady devices operate under two constraints: (1) The energy input must be equal to the energy output. (2) The device's thermal inputs and outputs must increase the entropy of the environment (or leave it unaltered).

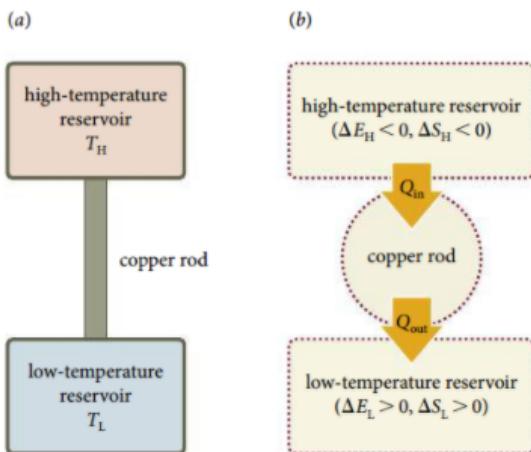
(b) Attempt to convert thermal energy entirely to mechanical energy



Mazur 21.2 Quality of energy

-Heat transfer through rod between reservoir

Figure 21.9 (a) A copper rod in thermal contact with a high-temperature reservoir and a low-temperature reservoir. (b) Energy input-output diagrams for the rod and the reservoirs.



-where

$$\Delta S_H + \Delta S_L > 0$$

-Entropy Gradient (for Steady Devices)

Figure 21.10 Entropy gradient. The shaded bar represents the rod's environment, which consists of the high-temperature reservoir (H) and the low-temperature reservoir (L).

Entropy gradient measures change in entropy for a given change in energy.

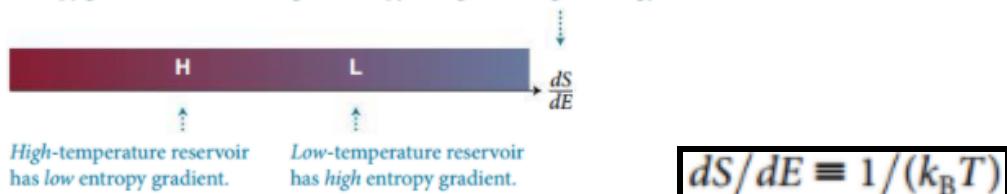
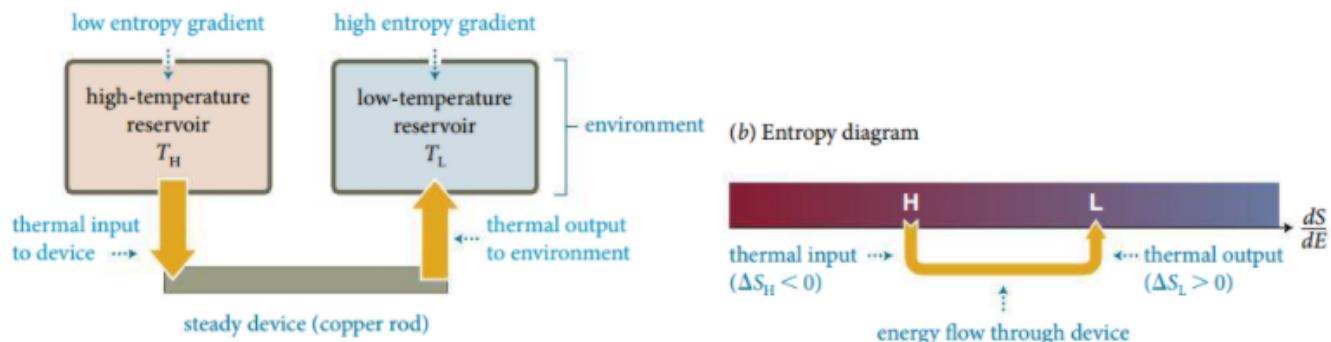


Figure 21.11 (a) We rearrange the device of Figure 21.9 to separate the system (the steady device) from its environment (the thermal reservoirs). (b) Using this geometry, we construct an entropy diagram showing the energy conversions and transfers in the steady device. The thermal input at low dS/dE causes entropy change in the environment of smaller magnitude than thermal output at high dS/dE , so the entropy of the environment increases: $\Delta S_H + \Delta S_L > 0$.

(a) We separate the device (the system) from its environment



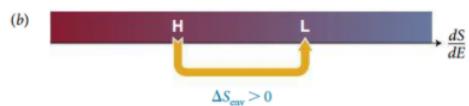
-Energy flow can't go from L to H because that is a positive S change.

Figure 21.16 Energy with a large entropy gradient is less useful and therefore of lower quality than energy with a small entropy gradient.

Relationship of entropy gradient to quality of energy



Process that degrades energy quality



Process that upgrades energy quality (not possible on its own)

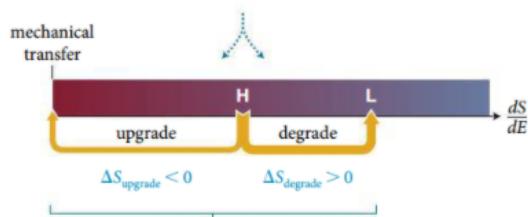


Mazur 21.3 Heat engine and heat pump

-Heat Engine

Figure 21.18 Entropy diagram for a process that upgrades and degrades energy.

Steady device splits thermal input. Part is upgraded to mechanical energy; rest is degraded.



Entropy of environment increases or stays the same:

$$\Delta S_{env} = \Delta S_{upgrade} + \Delta S_{degrade} \geq 0$$

-Entropy doesn't decrease from the upgrade and degrade.

Figure 21.19 Energy input-output diagram for an automobile engine, which is one type of heat engine.

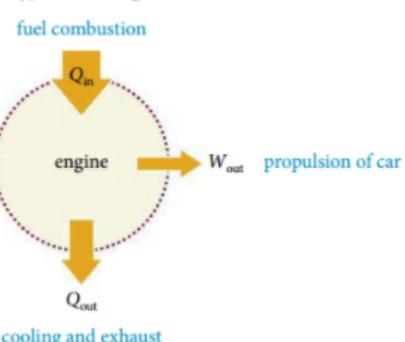
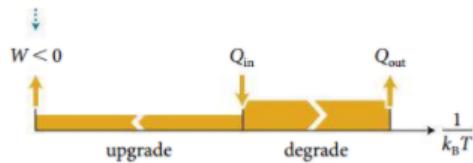


Figure 21.21 Entropy diagram for a process that upgrades and degrades energy (compare with Figure 21.18).

mechanical output of energy from system (upward arrow):
 $W < 0$ because $W =$ work done *on* system

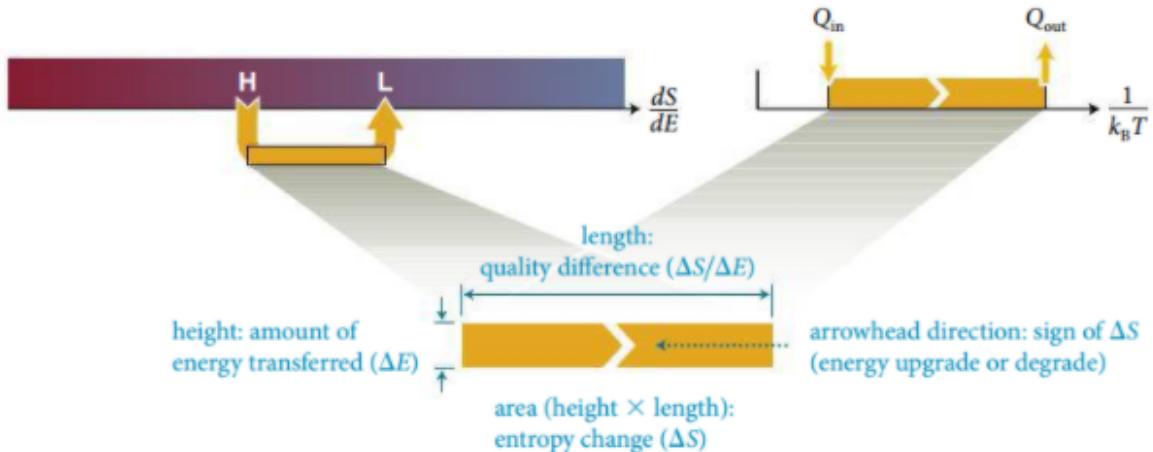


-Area is Entropy Change & Height is Change in Energy

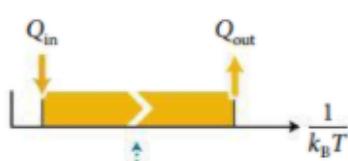
Figure 21.20 Obtaining entropy changes from entropy diagrams.

(a) Entropy diagram

(b) Simplified entropy diagram

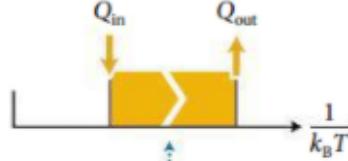


(c)



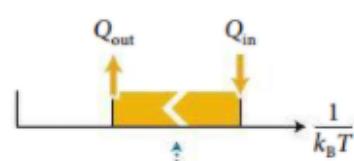
long rectangle:
large quality difference $\Delta S/\Delta E$

(d)



tall rectangle: large amount
of transferred energy ΔE

(e)



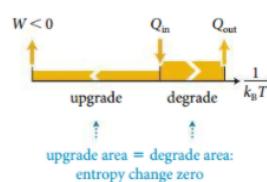
left-pointing arrowhead:
energy upgraded ($\Delta S < 0$)

same area: same entropy change ΔS

-Reversible

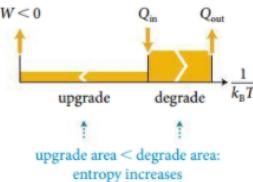
Figure 21.22 For a steady device, the entropy change in the environment must be greater than or equal to zero.

(a) Reversible process:
entropy change = 0



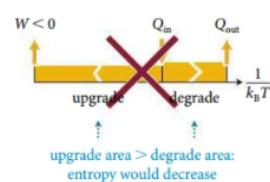
upgrade area = degrade area:
entropy change zero

(b) Irreversible process:
entropy change > 0



upgrade area < degrade area:
entropy increases

(c) Impossible process:
entropy change < 0

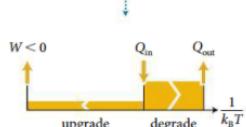


upgrade area > degrade area:
entropy would decrease

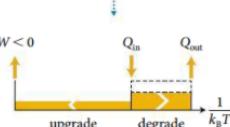
-Irreversible

Figure 21.23 Entropy diagram for an irreversible process.

An irreversible process . . .



. . . consists of a reversible process . . .



. . . superimposed on an irreversible energy degradation . . .

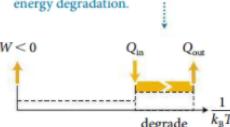
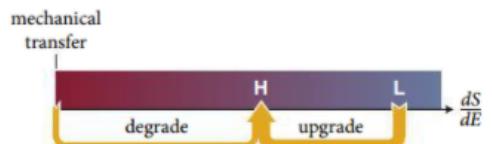
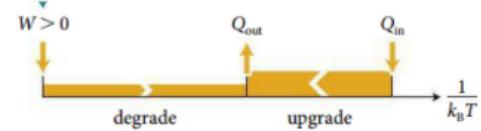


Figure 21.25 Energy conversions in a heat pump.

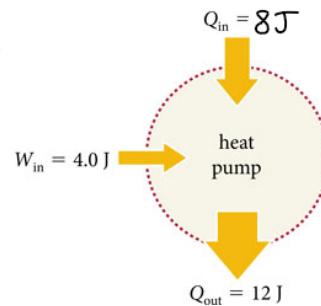
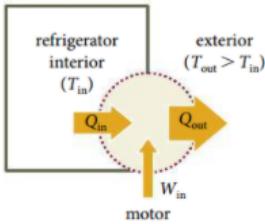
(a) Entropy diagrams for energy conversions in heat pump



mechanical input of energy to system
 $W > 0$ because $W = \text{work done on system}$



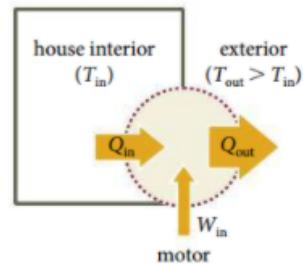
(b) Energy input-output diagram for refrigerator (a type of heat pump)



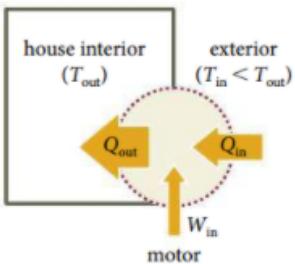
-Heat In is less than Heat Out unlike a Heat Engine.

Figure 21.26 A heat pump can serve as an air-conditioner in summer by removing energy from inside the house and as a heater in winter by transferring energy thermally from outside to inside the house.

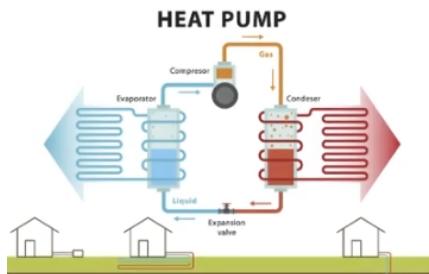
(a) Summer



(b) Winter



10.2 Lectures: Heat pumps

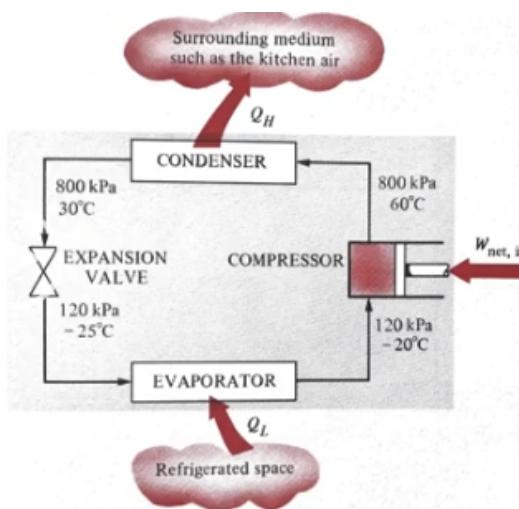


-Use work to transfer heat, especially cold areas to hot areas?

-Refrigerators

-Just a heat engine in reverse 4head.

- A refrigerator is really just a heat engine run in reverse.
- External energy is used to do work on the working fluid in the compressor.
- This raises the temperature of the working fluid enough to transfer heat energy out of the system in the condenser.
- Then the working fluid is decompressed which lowers its temperature.
- The low-temperature fluid then absorbs heat energy from the space to be refrigerated.



-A/C unit is where refrigerated space is your room & the condenser gives heat out to the outside.

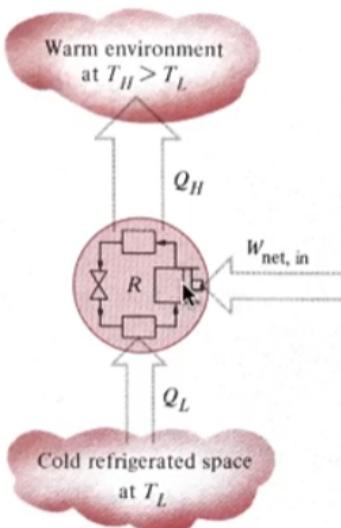
-Turning the A/C around

-It is a heat pump, where heat energy is let in from the outside.

-Coefficient of performance for heating

-Output is Q_H

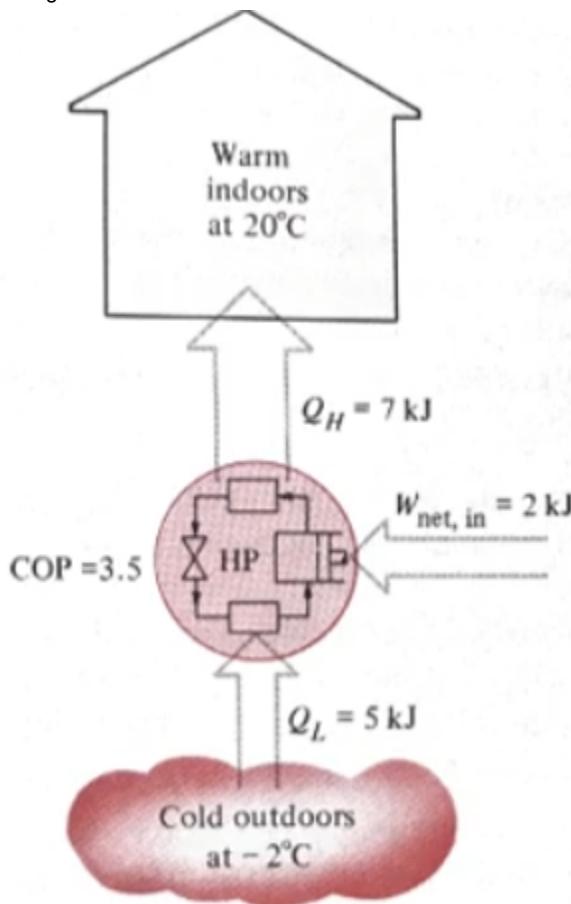
-Input is W_{net} (Q_L doesn't matter because we only supply work for the heat output)



So the efficiency is $\frac{Q_H}{W}$

The coefficient of performance of heating of a heat pump is defined as the ratio of the thermal output of energy (the energy delivered thermally to the space that must be heated) to the work done on the heat pump.

-Example heating house



$$\text{COP}_{\text{heating}} = \frac{Q_H}{W} = \frac{7 \text{ kJ}}{2 \text{ kJ}} = 3.5$$

$$Q_L + W = Q_H$$

-Alternative way for Coefficient of performance for heating

$$\text{COP}_{\text{heating}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}}$$

-Coefficient of performance for cooling

-The output is the lower heat. So...

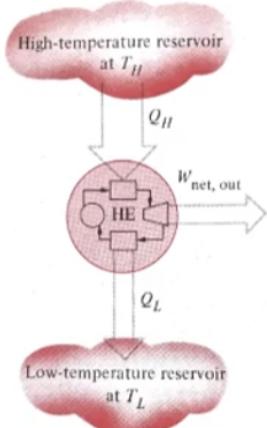
$$\text{COP}_{\text{cooling}} = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1}$$

-Reversibility Heat pump

-If system is reversible, no entropy change

$$\Delta S_{env} = 0 \text{ then } \frac{Q_H}{T_H} = \frac{Q_L}{T_L} \text{ and } \frac{Q_H}{Q_L} = \frac{T_H}{T_L}$$

-Theoretical limit for efficiencies (so this is for heat engine)

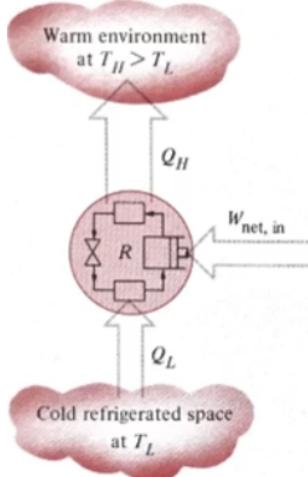


$$\text{If, for a reversible process, } \frac{Q_H}{Q_L} = \frac{T_H}{T_L}$$

$$\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H} \text{ (reversible)}$$

- Notice that this depends only on the temperatures of the two thermal reservoirs.
- Also notice that greater efficiency results from a greater temperature difference.

-Theoretical limit for Coefficients of performance



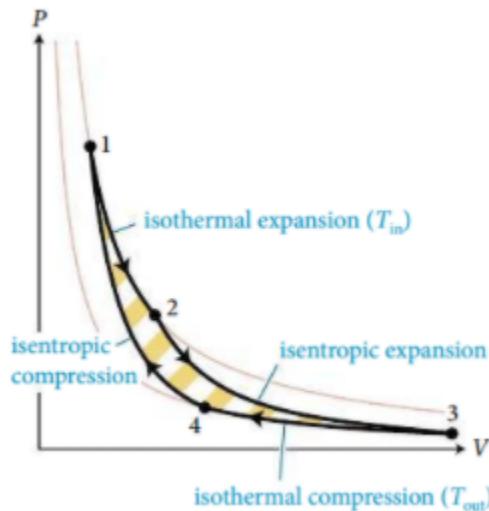
$$\text{If, for a reversible process, } \frac{Q_H}{Q_L} = \frac{T_H}{T_L}$$

$$\text{COP}_{\text{heating}} = \frac{1}{1 - \frac{Q_L}{Q_H}} = \frac{1}{1 - \frac{T_L}{T_H}} \text{ (reversible)}$$

$$\text{COP}_{\text{cooling}} = \frac{1}{\frac{Q_H}{Q_L} - 1} = \frac{1}{\frac{T_H}{T_L} - 1} \text{ (reversible)}$$

-Carnot cycle

-Reversible process that has 2 isoT & isentropic ($Q=0$) processes.



Process	Definition	ΔS_{dev}	ΔE	W	Q
1 → 2 (isothermal)	$\Delta T = 0$	$N \ln\left(\frac{V_2}{V_1}\right)$	0	$-Nk_B T_{in} \ln\left(\frac{V_2}{V_1}\right)$	$Nk_B T_{in} \ln\left(\frac{V_2}{V_1}\right)$
2 → 3 (isentropic)	$Q = 0$	0	$NC_V(T_{out} - T_{in})$	$NC_V(T_{out} - T_{in})$	0
3 → 4 (isothermal)	$\Delta T = 0$	$N \ln\left(\frac{V_4}{V_3}\right)$	0	$-Nk_B T_{out} \ln\left(\frac{V_4}{V_3}\right)$	$Nk_B T_{out} \ln\left(\frac{V_4}{V_3}\right)$
4 → 1 (isentropic)	$Q = 0$	0	$NC_V(T_{in} - T_{out})$	$NC_V(T_{in} - T_{out})$	0
cycle	reversible	0	0	$-Nk_B(T_{in} - T_{out}) \ln\left(\frac{V_2}{V_1}\right)$	$-W$

$$W = -Nk_B T_{in} \ln\left(\frac{V_2}{V_1}\right) - Nk_B T_{out} \ln\left(\frac{V_4}{V_3}\right)$$

$$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$

$$Q_{in} = Q_{1 \rightarrow 2} = Nk_B T_{in} \ln\left(\frac{V_2}{V_1}\right)$$

$$\eta = \frac{-W}{Q_{in}} = \frac{Nk_B(T_{in} - T_{out}) \ln\left(\frac{V_2}{V_1}\right)}{Nk_B T_{in} \ln\left(\frac{V_2}{V_1}\right)} = \frac{T_{in} - T_{out}}{T_{in}}$$

-Relationship between P&V

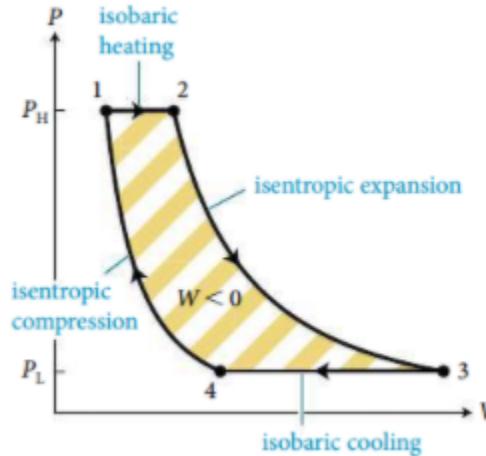
$$P_2 V_2^\gamma = P_3 V_3^\gamma \text{ (gamma is a coefficient capacity depending on gas)}$$

-Going different direction gives neg/pos work

-Not practical because work is usually small because the processes have to be slow to be reversible. (It is most efficient in theory or if u can wait forever)

-Brayton Cycle

-Reversible process that has 2 isoP & 2 isentropic ($Q=0$) processes



Process	Definition	ΔS_{dev}	ΔE	W	Q
1 \rightarrow 2 (isobaric)	$\Delta P = 0$	$\frac{NC_p}{k_B} \ln\left(\frac{T_2}{T_1}\right)$	$NC_V(T_2 - T_1)$	$-Nk_B(T_2 - T_1)$	$NC_p(T_2 - T_1)$
2 \rightarrow 3 (isentropic)	$Q = 0$	0	$NC_V(T_3 - T_2)$	$NC_V(T_3 - T_2)$	0
3 \rightarrow 4 (isobaric)	$\Delta P = 0$	$\frac{NC_p}{k_B} \ln\left(\frac{T_4}{T_3}\right)$	$NC_V(T_4 - T_3)$	$-Nk_B(T_4 - T_3)$	$NC_p(T_4 - T_3)$
4 \rightarrow 1 (isentropic)	$Q = 0$	0	$NC_V(T_1 - T_4)$	$NC_V(T_1 - T_4)$	0
cycle	reversible	0	0	$-Q$	$NC_p(T_2 - T_1 + T_4 - T_3)$

$$W = -Q = -NC_p(T_2 - T_1 + T_4 - T_3)$$

$$\eta \equiv \frac{-W}{Q_{in}} = \frac{T_2 - T_1 + T_4 - T_3}{T_2 - T_1} = 1 - \frac{T_3 - T_4}{T_2 - T_1} = 1 - \frac{T_4}{T_1} \left[\frac{(T_3/T_4) - 1}{(T_2/T_1) - 1} \right] = 1 - \frac{T_4}{T_1} = 1 - \left(\frac{P_H}{P_L} \right)^{(1/\gamma)-1}$$

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \quad \frac{T_4}{T_1} = \left(\frac{P_H}{P_L} \right)^{(1/\gamma)-1}$$

$$\text{gamma} = C_p/C_V$$

-Approximation of gas turbine engine and jet engine.

-Greatest work on gas

The greatest amount of work is done on the gas in the cycle in which the gas does the least amount of work on the environment.