**Today:**

**Finish Vibrations and Waves (Ch 19)**

**Sound (Ch 20)**

## Preliminaries

- What is the origin of sound?

  **Vibrations** of objects. Eg. of a string, of a reed, of vocal cords..

Usually the small vibration stimulates vibration of a larger object eg. of the air, that then propagates through surroundings in form of **longitudinal waves**.

- Usually **frequency** of original vibration = frequency of sound waves = **pitch**
- High pitch means high frequency (eg a piccolo), whereas low pitch means low frequency (eg fog horn)

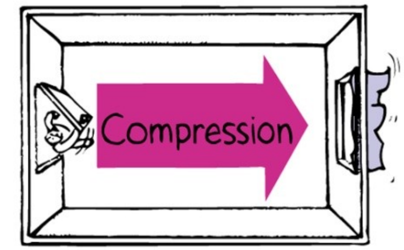
- Human ear can hear between 20 – 20 000 Hz.

- Infrasonic – below 20 Hz
- Ultrasonic – above 20 000 Hz

# How does sound travel in air?

- Longitudinal wave – air molecules vibrate to and fro along direction of wave
- Analogy with opening and shutting a door periodically:

Open door inward: a **compression** travels across room (via molecules pushing neighbors)

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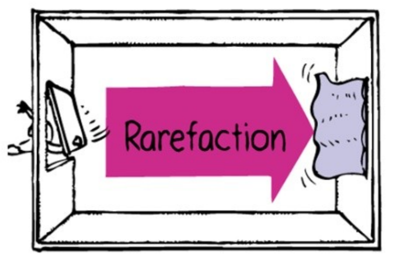


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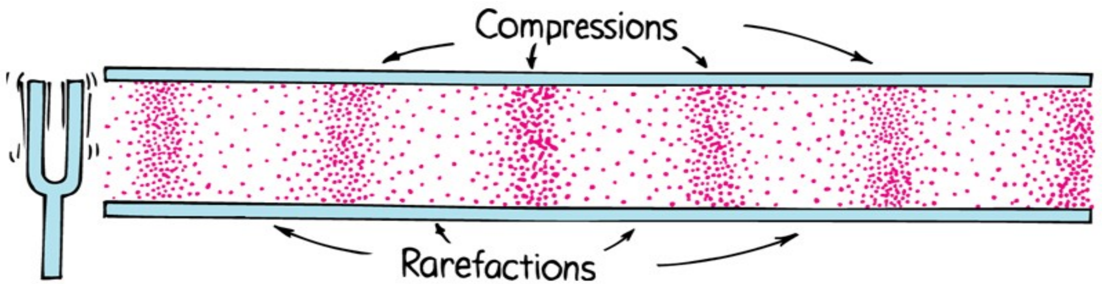
Close door: a **rarefaction** travels across room – some molecs are pushed out of room so leave lower pressure behind.

Swing door open and shut periodically – get periodic compression-rarefaction wave across the room.

*Note again*: medium (air molecules) are *not* transported across the room; rather the disturbance, and energy, are.

# How sound travels in air, continued…

- Tuning fork – is exactly this action on a smaller, faster scale: prong vibrating is like the door opening and shutting.






- Radio loudspeaker – cone that vibrates in synch with electric signal, causing neighboring air molecules to vibrate …eventually sound wave filling the room

- *Note:* compression and rarefaction travel in the *same* direction

# Clicker Question

Sound waves cannot travel in

A) air.

B) water.

C) steel.

D) a vacuum.

E)  any of the above media

Answer: D

Sound is transmitted via periodic compression and rarefaction of the medium – if nothing there, this can't happen.

# Speed of sound in air

- In dry air, at 0oC, speed of sound ~ 330 m/s ~ 1200 km/h
  At sea-level and temp, speed ~ 340 m/s
- Increased speed if - air is moist
  - air is warmer: Speed goes up 0.6 m/s for every oC
  - if wind is blowing between source and receiver
- Speed does *not* depend on loudness (amplitude), nor on pitch (frequency).
- Speed of light is a million times as great
  - Hence, we see lightning before we hear thunder
  - Hence, we see a distant tree fall to the ground before we hear the thud…
- Note that low and high pitches all have the same speed – they differ in frequency and wavelength (long for low, short for high), such that the product frequency x wavelength = *v* is same.

# Sound travels in other media too

- Doesn't have to be air – just has to have an **elastic** property i.e be able to change shape in response to an applied force and then resume its original shape once force is removed.

E.g. putty is not elastic but steel is

- Sound generally travels fastest in solids, then in liquids, and slowest in gases

E.g. 15x as fast in steel c.f. air and 4x as fast in water c.f. air

- Also, generally less dissipation (ie fading away) in solids and liquids than in air,

E.g. Can hear the slight rattles a distant train makes on the rails before you hear it's noise from the air

E.g. Motors of boats –or fingernails clicking - sound much louder to someone under water, than to someone above.

i.e. Liquids and crystalline solids are much better **conductors** of sound.

- Sound needs a medium – won't travel in a vacuum since nothing to compress and expand

# Clicker Question


i.e. frequency

Does the wind affect the pitch of a factory whistle you hear on a windy day?

1. Yes
2. No

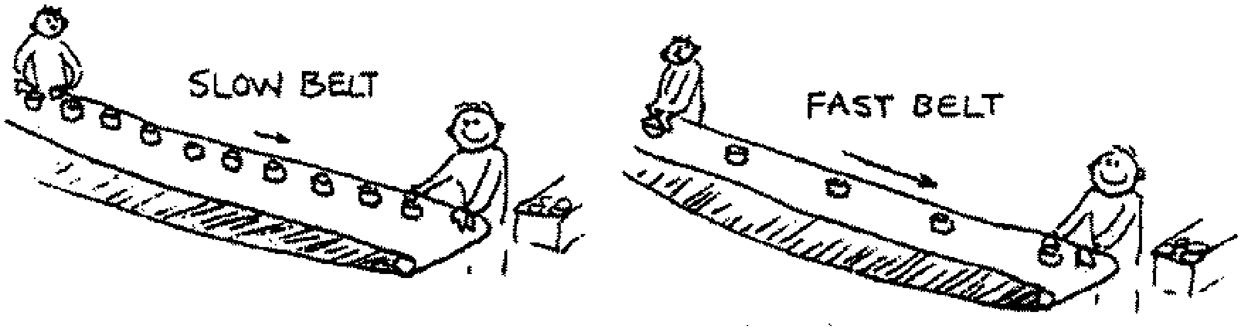
**Answer: 2**

The wind does not affect the pitch. The wind does affect the speed of sound because the medium that carries the sound moves. But the wavelength of the sound changes accordingly, which results in no change in frequency or pitch. This can be seen by analogy:

Does the wind affect the pitch of a factory whistle you hear on a windy day?

1. Yes
2. **No** ✔

Suppose a friend is placing packages on a conveyor belt, say at a "frequency" of one second. Then you, at the other end of the belt, remove one package each second. Suppose the speed of the belt increases while your friend still places one package per second on the belt. Can you see that the packages (farther apart now) will still arrive to you at the rate of one per second?



# Question

Some people claim they have an extra-sensory perception, citing the fact that they awaken from a deep sleep for no reason, get out of bed and walk to the window just in time to hear explosions from a distant munitions plant.

Clairvoyance??

Actually, can explain by comparing the *speed of sound* through earth and through air! Assume the tremor of the sound wave traveling through earth awoke the person, who then walked to the window just in time to hear the sound wave traveling through the air.

Sound travels through rock at 3000 m/s, and through air at 340 m/s. If the munitions plant is 1 km away, calculate the time interval between the tremor waking the person and him hearing it through the air.

Speed = distance/time, so time = distance/speed.

So time through rock = (1000m)/(3000 m/s) = 0.33 s

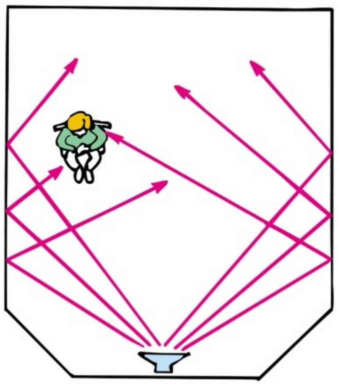
Time through air = (1000 m)/(340 m/s) = 2.94 s

So time interval = 2.94 -0.33 = 2.6 s

# Reflection of Sound

The smoother the surface, the more is reflected, less absorbed

- Called an **echo**
- When wave strikes a surface, some is **reflected** and some is **transmitted** (i.e. absorbed)



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- Reflection rule:

Angle of incidence = angle of reflection

(same for light and sound)

- Can get multiple reflections - called ***reverberations*** – when sound reflects off from one surface onto another and then another…

Causes garbling of sound. Can lessen if surfaces are dampened – i.e. if use material that absorbs more and reflects less. But then also quieter.

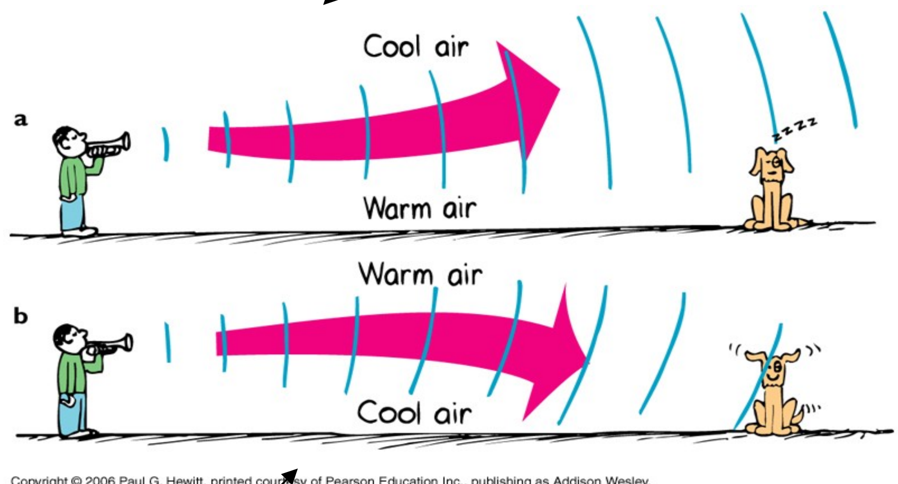
- Good concert halls need to balance the two effects – study of **acoustics.**
- Sometimes use plastic reflectors above orchestra –if you can see the musician, likely you can hear their music, since same reflection rule.

# Refraction of sound

- Means **bending.**
- Happens when parts of the wave front travel at **different speeds** eg through windy air or air of varying temperatures:

warm day – air often warmer closer to the ground

Speed of sound is faster in warm air than cold, so effectively bends from warm toward the cool air.




Explains why sometimes we don't hear thunder from far away lightning – cooler air above, so sound bent away from ground.

cold day or at night, air is colder near ground

# More on refraction/reflection…

- Refraction happens under water, due to varying water temp – can be problematic for vessels trying to chart sea bottom's features by bouncing ultrasonic waves off the ground.
- But it could be useful for submarines that don't want to be detected.

- Ultrasound procedure in medical diagnosis – ultrasonic waves strongly reflected from outside of organs, so can give a picture of the organs.

- If object is moving (eg a baby's heart) then the reflected wave is Doppler-shifted; measuring the shift can give baby's heartbeat, even when foetus is just 10 weeks old!

- Dolphins and bats use ultrasound reflection/refraction and Doppler effect to get a sense of their surroundings.

# Energy in sound waves

- Very small compared to other waves eg. 10 million people talking at the same time produces the same amount of sound energy as that needed to light a common flashlight!
- We can only hear because our ears are so sensitive.
- As sound travels, sound energy dissipates to thermal.
- Higher frequencies dissipate more rapidly than lower frequencies – hence you may hear the boom-boom drums from party music down the street but not the melody…

# Clicker Question

A foghorn warns vehicles of hazards or other boats in foggy conditions. Why does it have such a low pitch?

(a) Because low pitches travel faster than high pitches

(b) Because low pitches do not dissipate as quickly as high pitches

(c) Because high frequencies carry farther in air

(d) Because high frequencies travel faster

(e) None of the above

Answer: B

All sound eventually dissipates (gets transformed into heat etc) but low frequencies (= low pitches) dissipate slower than high frequencies.

# Forced vibrations

- When force an object to vibrate at a certain frequency

- Eg. Tuning fork (**DEMO**): bang it and hold in air, sound is quite faint. But if bang it, and then hold on table, the sound is louder, because table is forced to vibrate too – with its larger surface area, more air molecules made to vibrate…

# Natural Frequency

- Characteristic frequency (or frequencies) that an object tends to vibrate at, if disturbed. (But not forced by an external vibrating object)

E.g. Tuning fork, Wine glasses with different amounts of water – characteristic pitch

- Determined by elastic properties, shape etc of object – to do with structure. (So only elastic objects have natural freqs – putty does not)

- Not just a property of sound waves

Eg Pendulum has a natural frequency determined by its length – if released, will oscillate with that freq. (c.f. last lecture)

# Resonance

- Is when **frequency of forced vibration = object's natural frequency**
- A **dramatic increase in amplitude** results

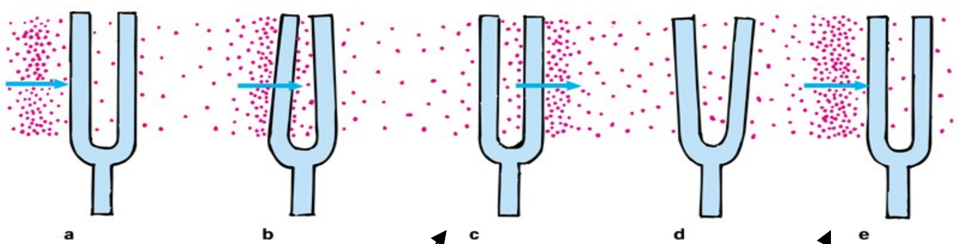
- Eg. Pumping legs when on a swing: pump in rhythm with the swing's natural freq, and you go higher.

Or, get someone to push you at in rhythm with swing - i.e. "in resonance"

Note that if you are pushed really forcefully but *not* in resonance, you don't go higher – timing is more important than force.

- **DEMO:** two separated sam… e other into vibration! Often c…

Here's what's happening to the second fork:






1st compression pushes fork in a tiny bit…

…on return, it meets 1st rarefaction, so moves out with greater amplitude – effects of natural freq and wave from 1st fork add.

Returns at time when another compression arrives – will move out yet further because already moving.

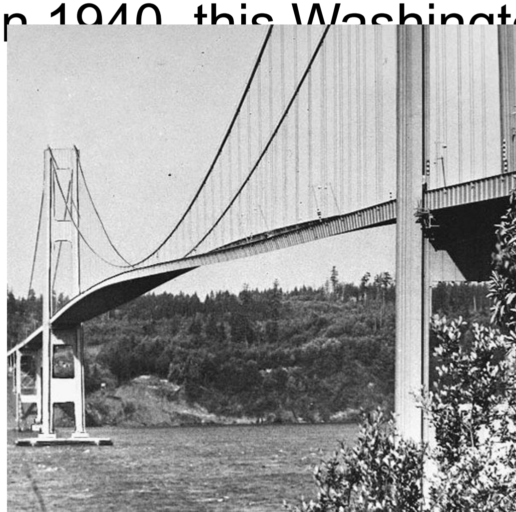
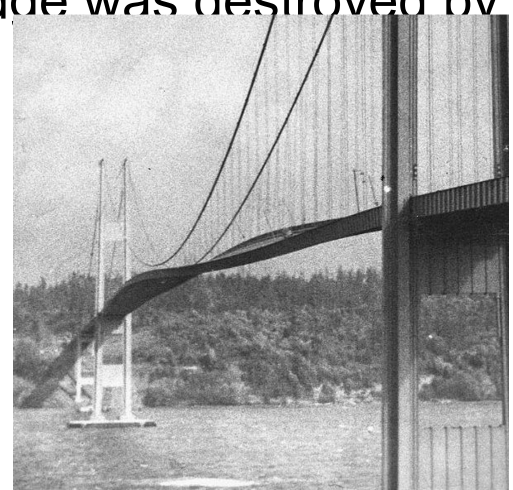
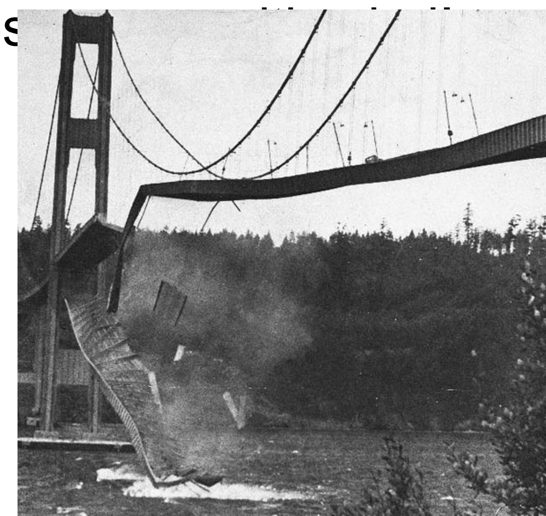
# Resonance continued

- Note that if the forks did not have matched frequencies, the timing of the pushes with the natural inclination of the second fork will be off; won't get increased amplitude.

- Same principle when tune your radio!
- Very  important in musical instrument design.

- This is why soldiers "break step"  when crossing bridges: in 1831, British troops inadvertently marched in resonance (ie in rhythm) with the natural freq of a footbridge, breaking it.

- In 1940, this Washington bridge was destroyed by a res

# Clicker Question

Caruso is said to have made a crystal chandelier shatter with his voice. This is a demonstration of

A) sound refraction.

B) an echo.

C) sound reflection.

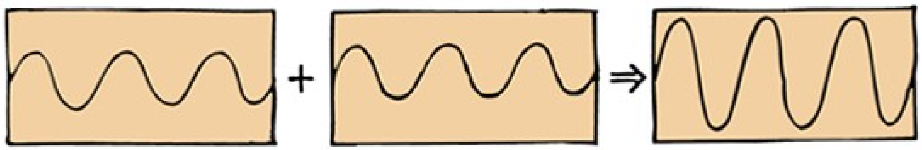
D) interference.

E) resonance.

Answer: E

# Interference

- Recall from Chap 19, but now applied to longitudinal waves too: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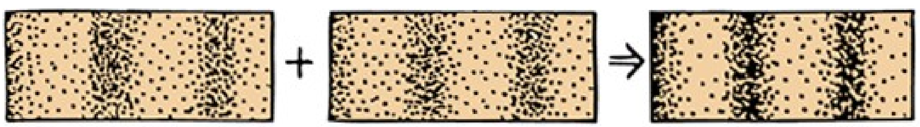
The superposition of two identical transverse waves in phase produces a wave of increased amplitude.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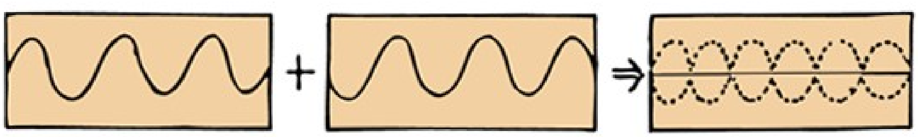
The superposition of two identical longitudinal waves in phase produces a wave of increased intensity.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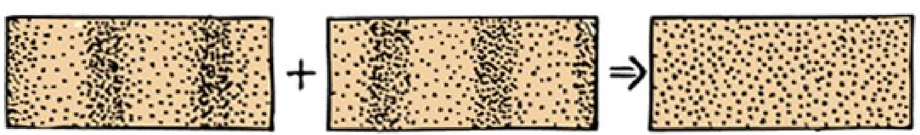
Two identical transverse waves that are out of phase destroy each other when they are superimposed.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Two identical longitudinal waves that are out of phase destroy each other when they are superimposed.

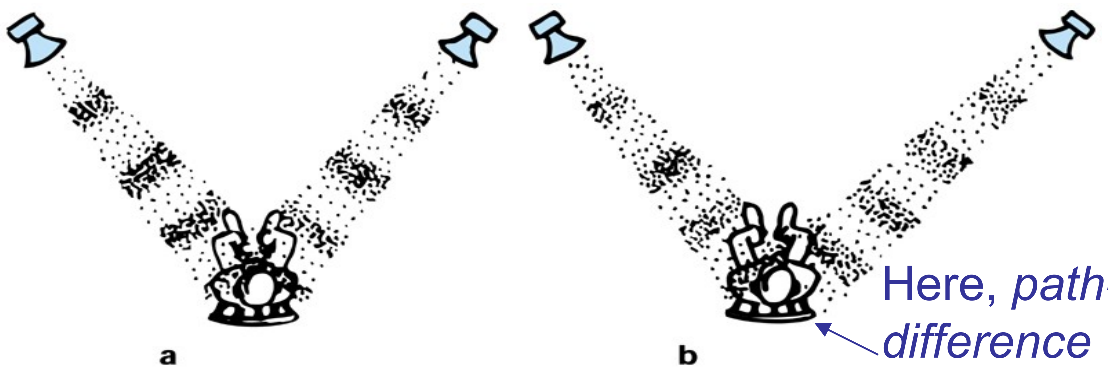
# Interference cont.

- Consider two speakers driven in synch by same frequency sound:

If sit equi-distant from each, then speakers add, sound is louder (picture a) – constructive interference.

If move a bit to one side, then compression of one meets rarefactions of other, sound is gone (picture b) – destructive interference.

actually, because of reflection from walls etc., you do hear a little sound






Here, *path-length difference* is half a wavelength

- Whether, for certain path-length difference, you get constructive or destructive, depends on the frequency.

- Usually speakers emit variety of frequencies – only some destructively interfere for a given path-length difference. So usually not a problem, esp. when reflecting surfaces around.

# More on interference

Another example you may be able to try at home: Consider driving two speakers with same signal, but switching the + and – inputs on one of them. This makes them out of phase.

Get almost no sound when brought face-to-face - destructive interference as compression regions from one overlap with rarefaction from other.



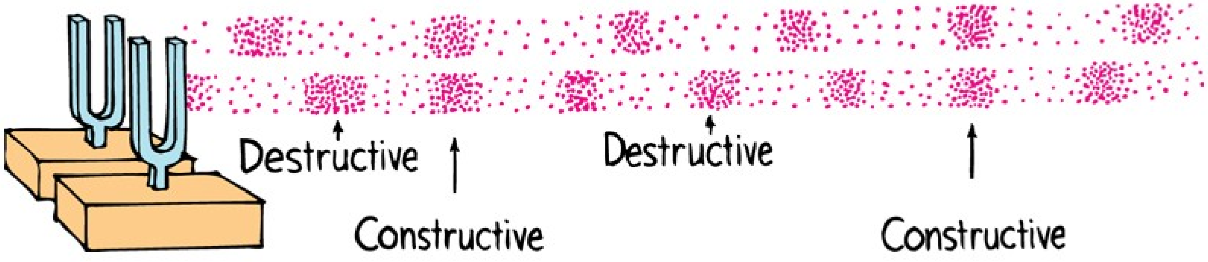
*At very short distances, you can hear very high frequencies – why?*

There is a very short path length difference, negligible effect for large wavelength $\lambda$ (low freq), so these destructively interfere. But for high freqs (short $\lambda$'s) if path-length diff is $\lambda/2$, then speakers become in phase.

- **Anti-noise technology** – need eg in jackhammers. Electronic microchips produce mirror-image wave patterns of the sound. This is fed to headphones, so to cancel out the loud noise for the operator, while enabling him to still hear co-workers voices!

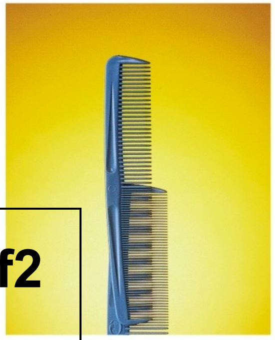
# Beats

- Are a **periodic variation in loudness (amplitude) –throbbing - due to two tones of slightly different frequency.**
- Arises from interference
- Eg. Two slightly mismatched tuning forks – compressions and rarefactions are periodically  in step, then out of step:






- Eg Analogy with two combs with slightly different teeth spacing:



- **Number of beats per second = Frequency difference = f1–f2**
- **Overall tone (pitch) heard = Frequency average**

# More on Beats

- Excellent demo at http://library.thinkquest.org/19537/java/Beats.html

- Useful for tuning musical instruments – listen for beats to disappear when freqs of instrument identical to a standard (tuning fork). (See Question shortly)

- Beats produced when incident wave interferes with a reflected wave from a moving object: reflected wave has Doppler-shifted frequency, so the two waves differ slightly in freq. Hear beats.

- Underlies how police radar in speed-detectors work, since Doppler shift, and therefore the beat frequency, is related to speed of car.

- Also underlies how dolphins use beats to sense motions

# Clicker Question

A violinist tuning her violin, plays her A-string while sounding a tuning fork at concert-A 440 Hz, and hears 4 beats per second. When she tightens the string (so increasing its freq), the beat frequency increases.

What should she do to tune the string to concert-A, and what was the original untuned freq of her string?

a) Tighten the string, original freq 436 Hz
b) Loosen the string, original freq 444 Hz
c) Tighten the string, original freq either 436 Hz or 444 Hz
d) Loosen the string, original freq either 436 Hz or 444 Hz
i) None of the above

Answer: B

Beat freq = 4 Hz, so orig freq is either 444 Hz or 436 Hz.

Increasing freq increases beat freq, so makes the difference with concert-A greater. So orig freq must have been 444 Hz, and she should loosen the string to tune it to concert-A.

# Question

A human cannot hear sound at freqs above 20 000 Hz. But if you walk into a room in which two sources are emitting sound waves at 100 kHz and 102 kHz you will hear sound. Why?

You are hearing the (much lower) beat frequency, 2 kHz = 2000 Hz.