Physics 115 Lecture 20

Reflection and Reverberation

March 9, 2018

Attenuation by absorption

- The wave intensity decreases due to *internal* friction among the molecules of the medium

- Attenuation is described by a bulk absorption coefficient called *m*:

$$I = I_0 e^{-2mx}$$

I = final intensity in W/m^2

I_0 = initial intensity in W/m^2

e = base of the natural logarithm

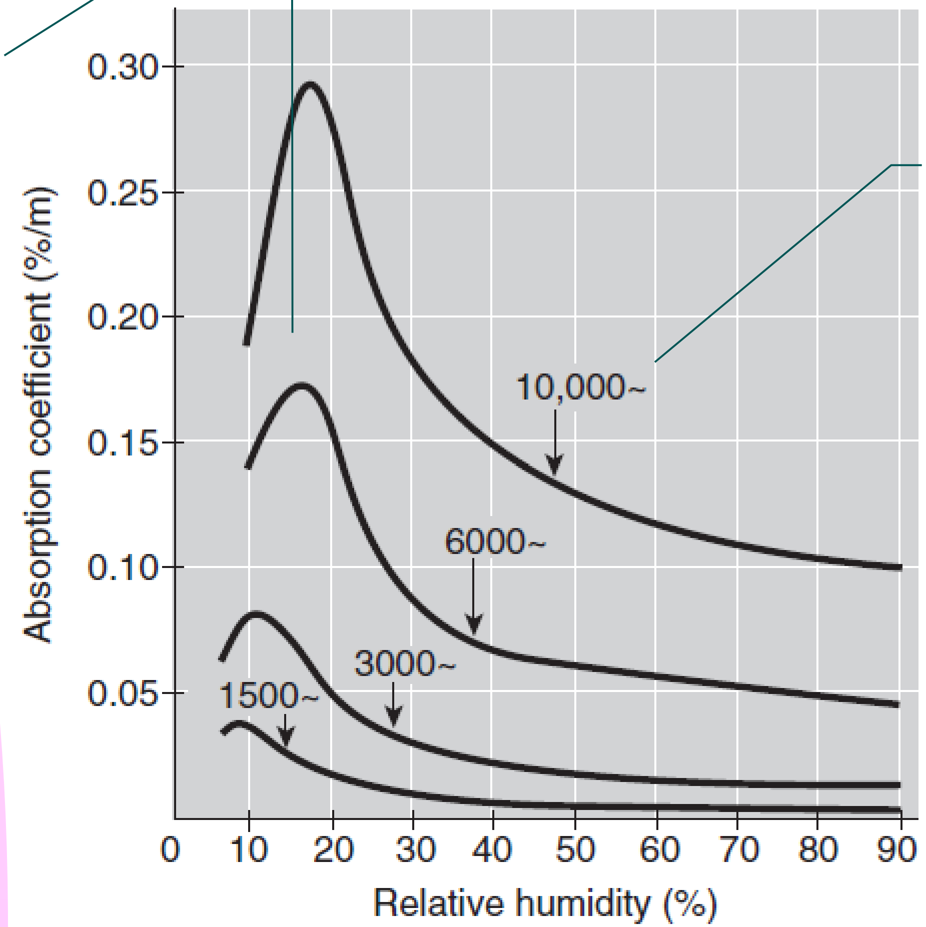
m = bulk absorption coefficient

x = distance the wave has traveled

Atmospheric absorption

- The amount by which air absorbs sound depends on frequency, relative humidity, and other factors.

Maximum absorption around 15% RH



High frequencies are attenuated more

Another (easier?) way to calculate

- The coefficients *m* for absorption in air are small. For instance, at 4000 Hz (peak sensitivity for human ear) at 20°C and 50% RH, $m = 0.00255\ \text{m}^{-1}$.
- The coefficient can also be expressed as decibels per kilometer

$$L = L_0 - a\,x$$

L_0 = initial sound level in decibels

L = final sound level in decibels

a = absorption coefficient in dB/km

x = distance in kilometers

The two are related (FYI only)

$$I = I_0 e^{-2mx} \quad m \text{ has units of 1/m}$$

$$\log(I/I_r) = \log(I_0/I_r) + \log\left(e^{-2mx}\right)$$

$$\log(I/I_r) = \log(I_0/I_r) - 2mx\log(e)$$

$$10\log(I/I_r) = 10\log(I_0/I_r) - 20mx\log(e)$$

$$L = L_0 - ax \quad \text{where}$$

$$a = 20m\log_{10}(e) \times \frac{1000\text{ m}}{\text{km}}$$

$$\boxed{a = 8686m \text{ dB/km}}$$

Example from Figure 6.1

- Interactive applet for finding absorption coefficient *a*.
- Figure 6.1 shows for 20°C, 20% relative humidity, f = 6000 Hz, that $m = 0.0016\ \mathrm{m}^{-1}$.

$$a = 8686\,m = 8686\left(0.0016\ \mathrm{m}^{-1}\right)$$

$$= 13.90\ \mathrm{dB/km}$$

- Wolfram value: 144.4 dB/km ($m = 0.0166\ \mathrm{m}^{-1}$)
- Handbook of Chemistry and Physics 1995: 134.98 dB/km at 6300 Hz ($m = 0.0155\ \mathrm{m}^{-1}$)
- I conclude that figure 6.1 *y*-axis labels should all be multiplied by ten. [publisher confirmed 3/12/2013]

Attenuation by reflection

- The wave intensity decreases due to partial absorption and transmission of the sound wave at a boundary (*external* absorption)

- Attenuation is described by a boundary "absorption" coefficient called *α*:

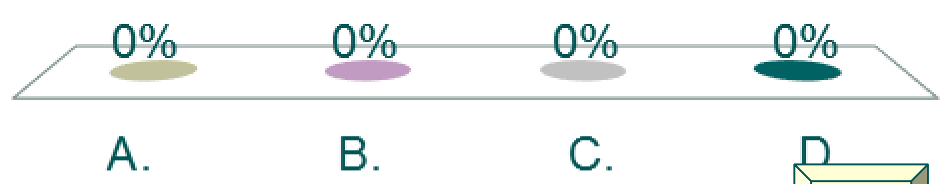
$$\alpha = \frac{\text{absorbed or transmitted intensity}}{\text{incident intensity}} = \frac{I_{\text{absorbed}}}{I_0}$$

$$\beta = \frac{\text{reflected intensity}}{\text{incident intensity}} = \frac{I_{\text{reflected}}}{I_0}$$

$$\alpha + \beta = 1 \text{ (total energy is conserved)}$$

A cap gun emits a sound wave of intensity $I_0 = 1.93 \times 10^{-7}$ W/m^2 after it has traveled 101 m. What will I be if absorption by a painted concrete wall is taken into account? Let $\alpha = 0.080$.

A. 4.17×10^{-5} W/m^2
B. 1.78×10^{-7} W/m^2
C. 9.69×10^{-8} W/m^2
D. 4.17×10^{-12} W/m^2



Response Counter

180

A cap gun emits a sound wave of intensity $I_0 = 1.93\times10^{-7}$ W/m^2 after it has traveled 101 m. What will I be if absorption by a painted concrete wall is taken into account? Let $\alpha = 0.080$.

A. 4.17×10^{-5} W/m^2

B. 1.78×10^{-7} W/m^2

C. 9.69×10^{-8} W/m^2

D. 4.17×10^{-12} W/m^2

$$\beta = 1 - \alpha = 1 - 0.080 = 0.92$$

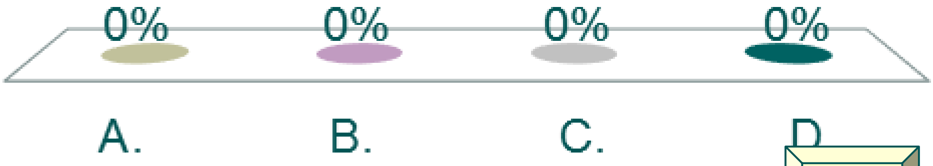
$$I_{\text{reflected}} = \beta I_0 = (0.92)\left(1.93\times10^{-7}\ \text{W/m}^2\right)$$

$$= \boxed{1.78\times10^{-7}\ \text{W/m}^2}$$

The reflection reduced the level from 52.9 dB to 52.5 dB

A cap gun emits a sound level L_0 = 52.5 dB after it has traveled 101 m and reflected from a concrete wall. What will *L* be if atmospheric absorption is taken into account?
Let *a* = 29.63 dB/km.

A. 2.99 dB
B. 18.7 dB
C. 49.5 dB
D. 52.9 dB



Response Counter

180

A cap gun emits a sound level L_0 = 52.5 dB after it has traveled 101 m and reflected from a concrete wall. What will L be if atmospheric absorption is taken into account? Let a = 29.63 dB/km.

A. 2.99 dB

B. 18.7 dB

C. 49.5 dB

D. 52.9 dB

$$L = L_0 - a\,x$$

$$= 52.5\text{ dB} - (29.63\text{ dB/km})(0.101\text{ km})$$

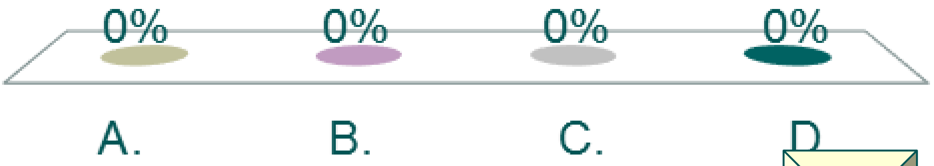
$$L = 52.5\text{ dB} - 2.99\text{ dB} = \boxed{49.5\text{ dB}}$$

We would get 52.9 dB if reflection and absorption not taken into account.

The values given in these examples are intended to be realistic for the cap gun experiment in the basement hallway last week. The temperature was assumed to be 20°C, RH 50%, f = 4000 Hz, a value from Wolfram web site, α from Table 6.1 p. 109 for painted concrete.

What happens to essentially all the sound energy in a dorm room after it is generated by a pair of stereo speakers?

A. It bounces around until it escapes out the window or door.
B. It is absorbed by your ears.
C. It is converted back to electrical energy by the speakers.
D. It heats up the room.



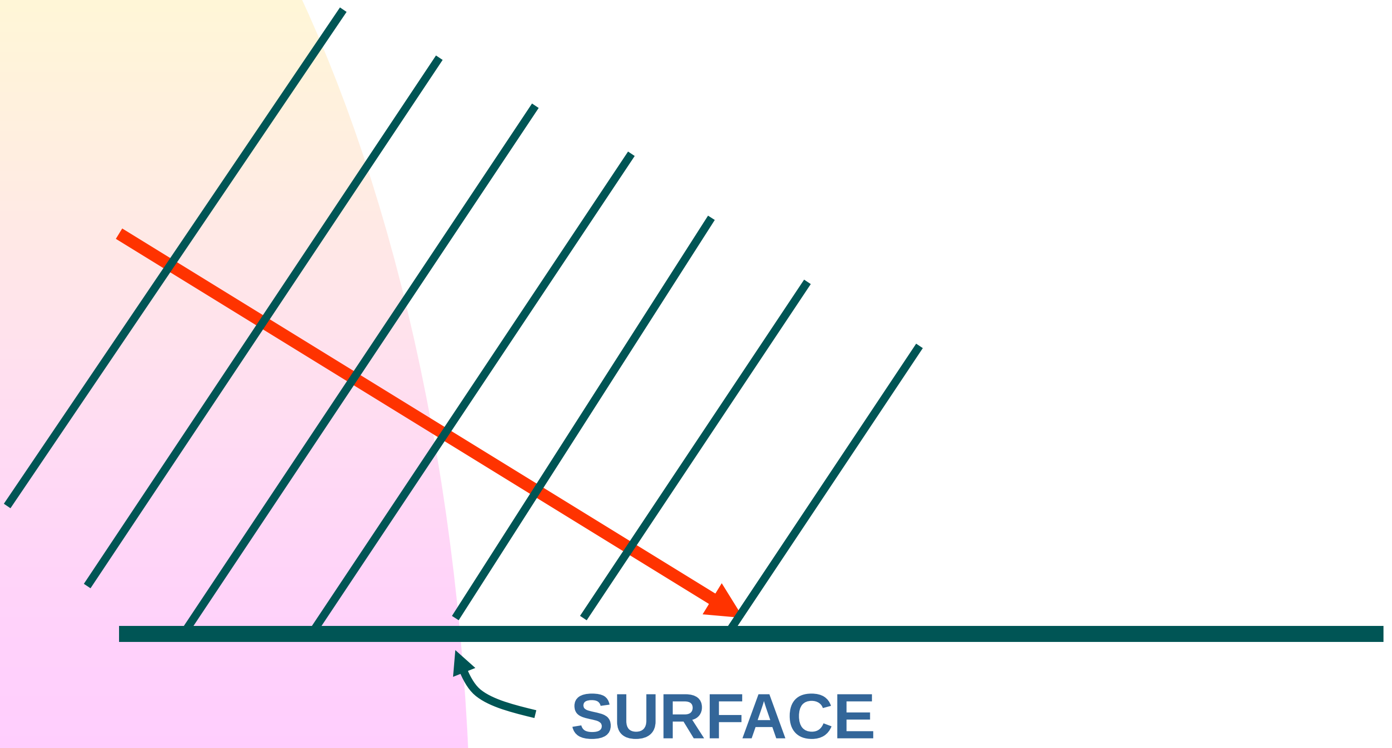
Response Counter

90

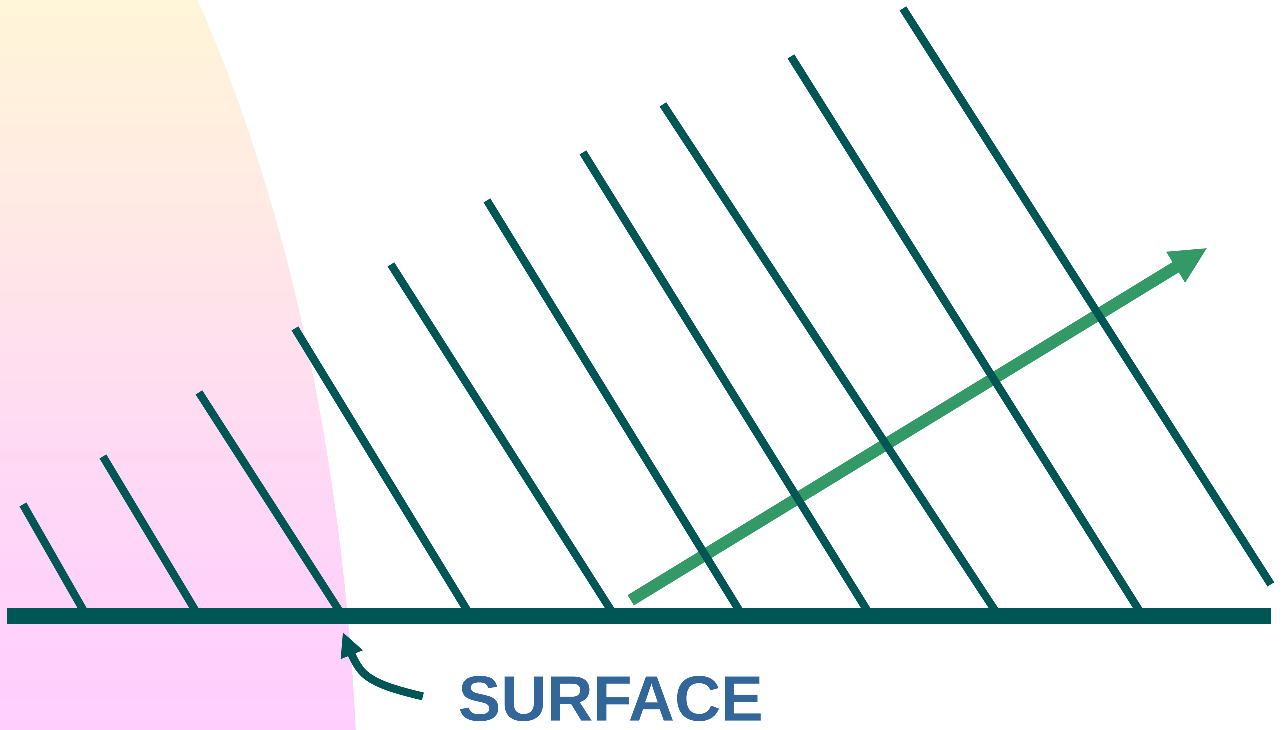
What happens to essentially all the sound energy in a dorm room after it is generated by a pair of stereo speakers?

A. It bounces around until it escapes out the window or door.
B. It is absorbed by your ears.
C. It is converted back to electrical energy by the speakers.
D. It heats up the room.

LAW OF REFLECTION



LAW OF REFLECTION



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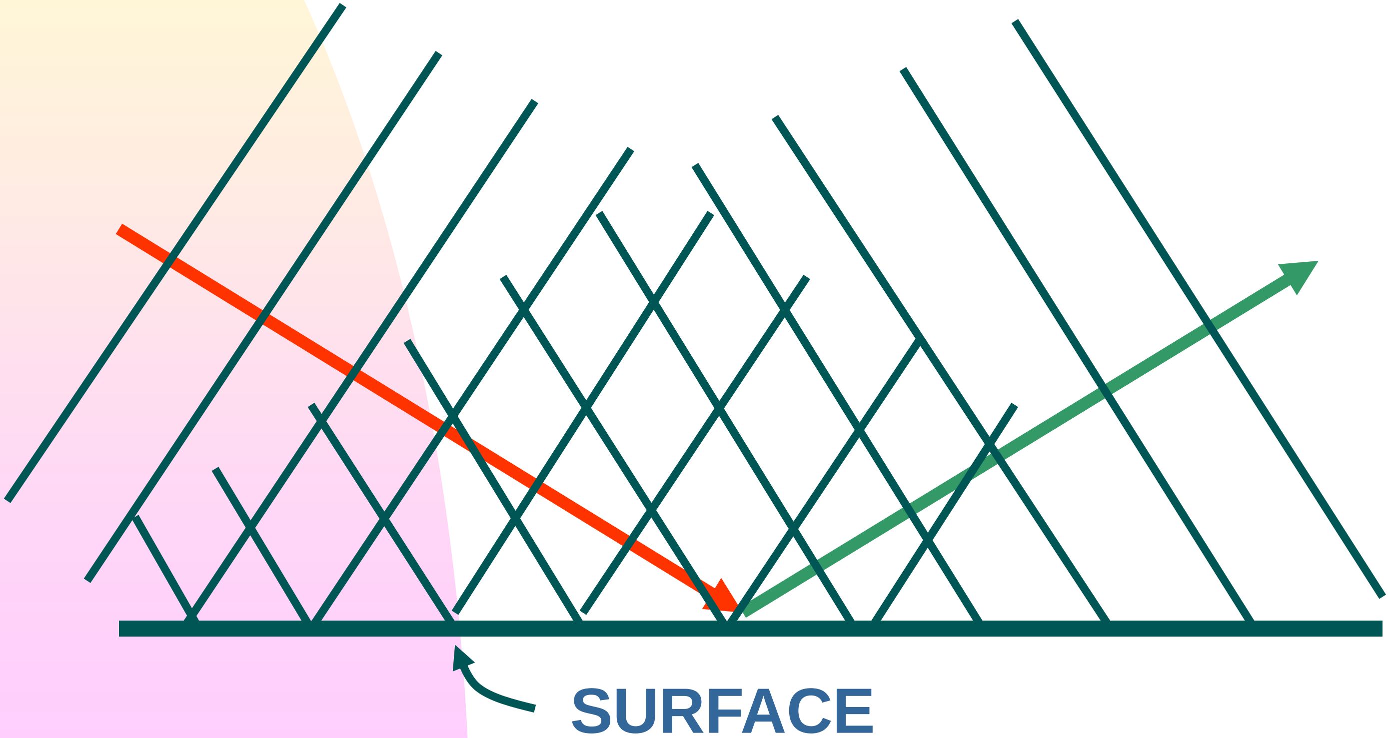

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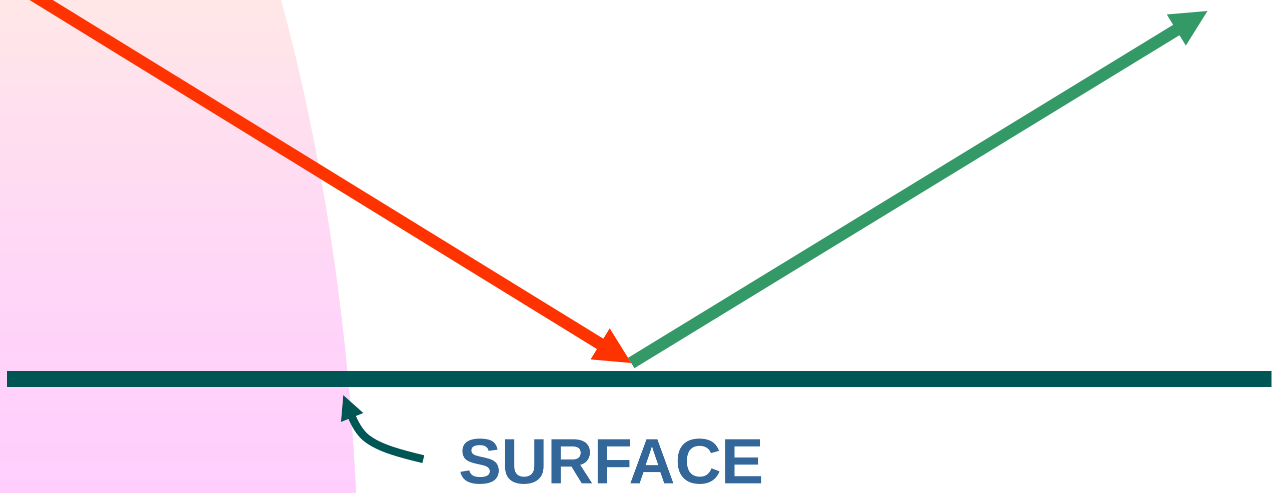
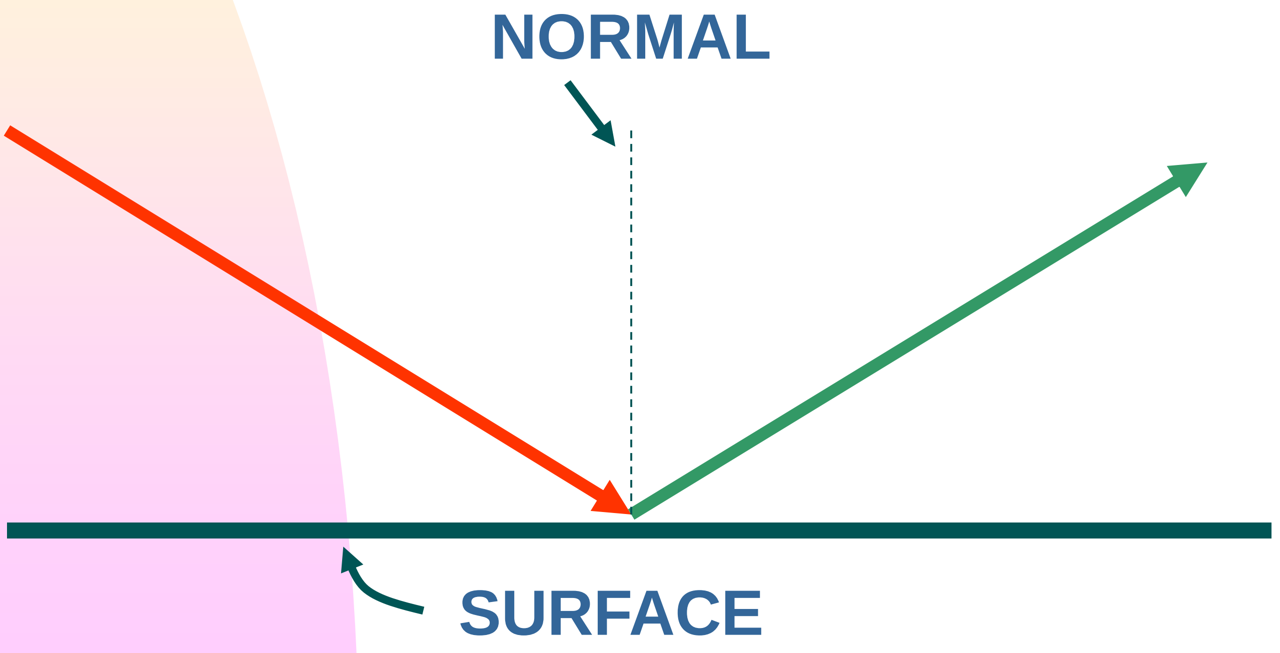


LAW OF REFLECTION



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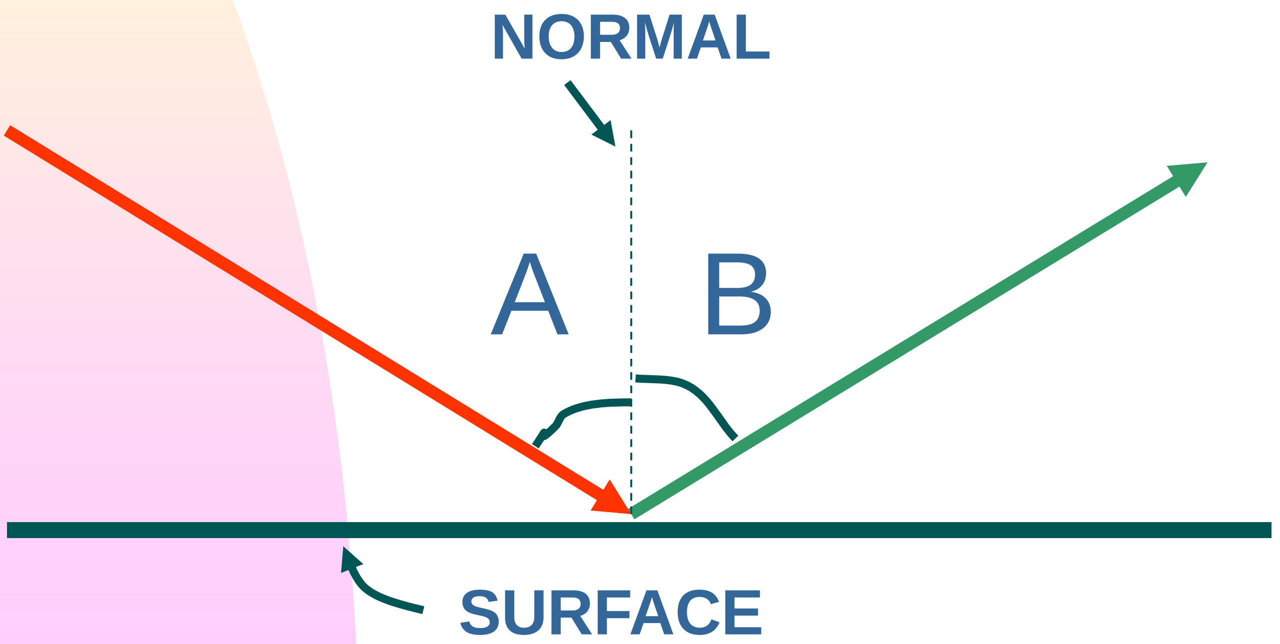
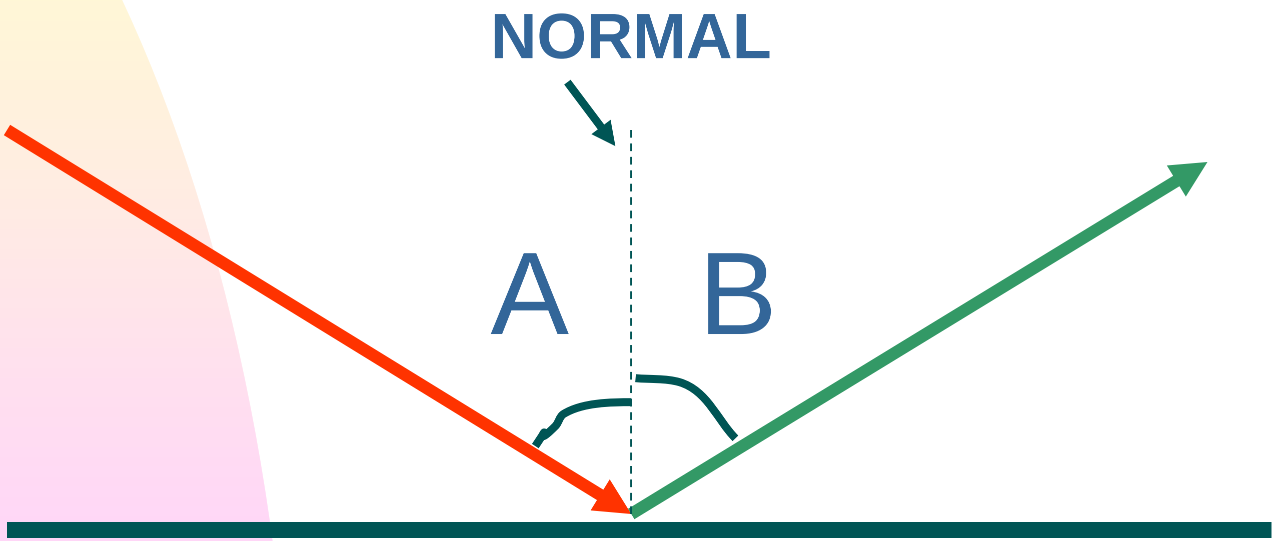


LAW OF REFLECTION

- ANGLE OF INCIDENCE = ANGLE OF REFLECTION

A=B



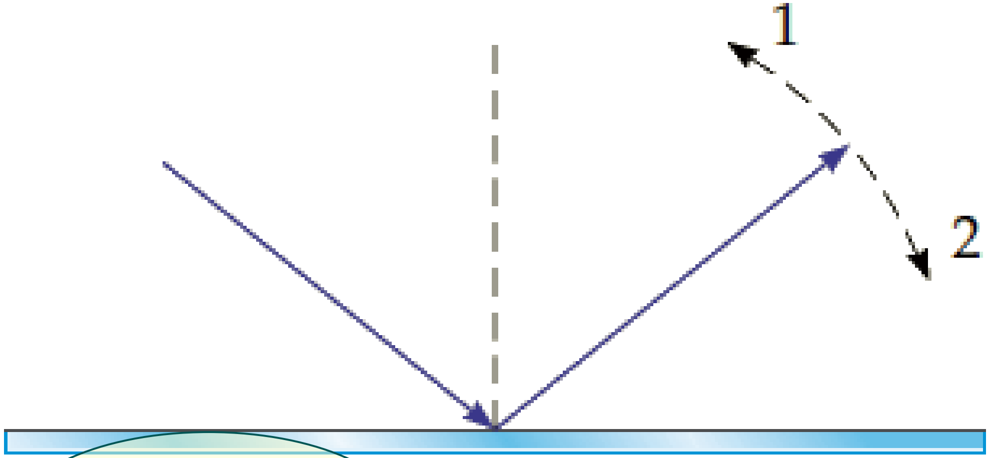
Interactive applet for law of reflection

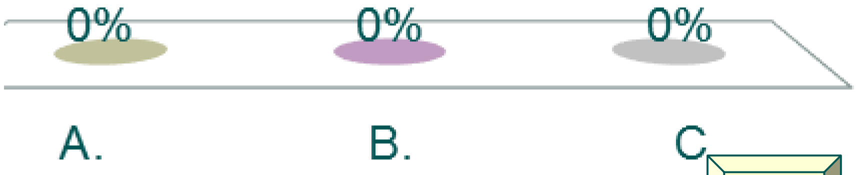
A beam of light reflects from a mirror as shown in the figure. If the angle of incidence of the beam is increased, the reflected beam

A. stays in the same direction

B. shifts in direction 1

C. shifts in direction 2





Response Counter

90

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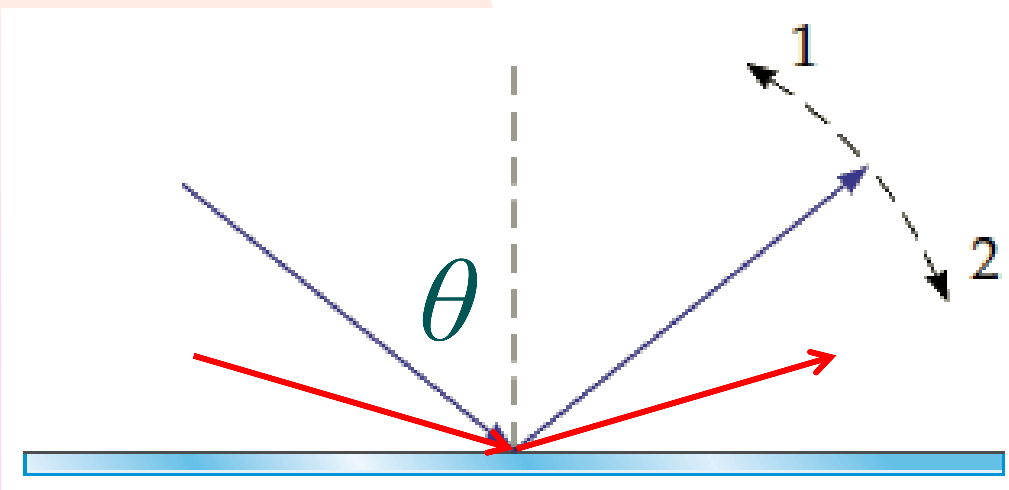
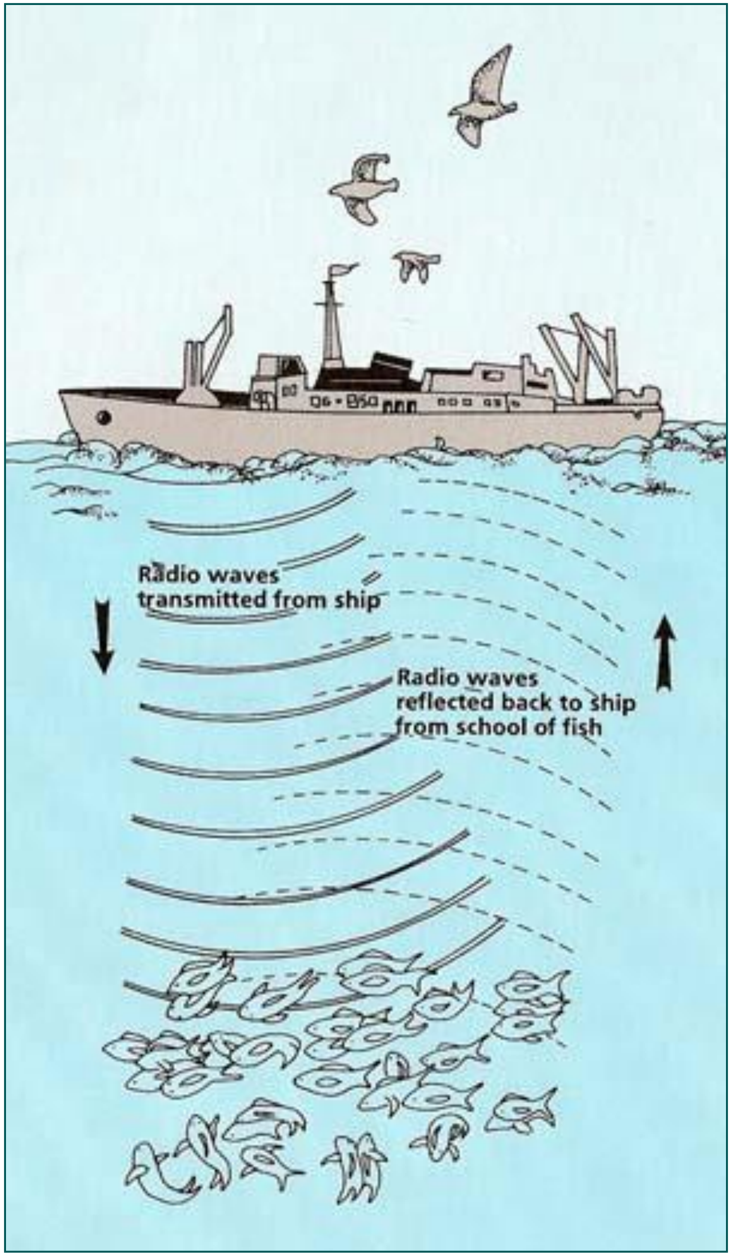
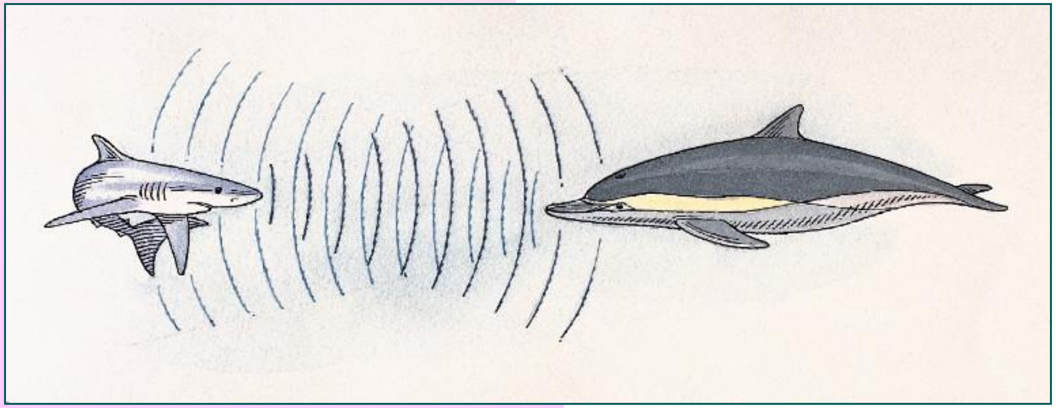


Reflection of sound waves: *ultrasound imaging*

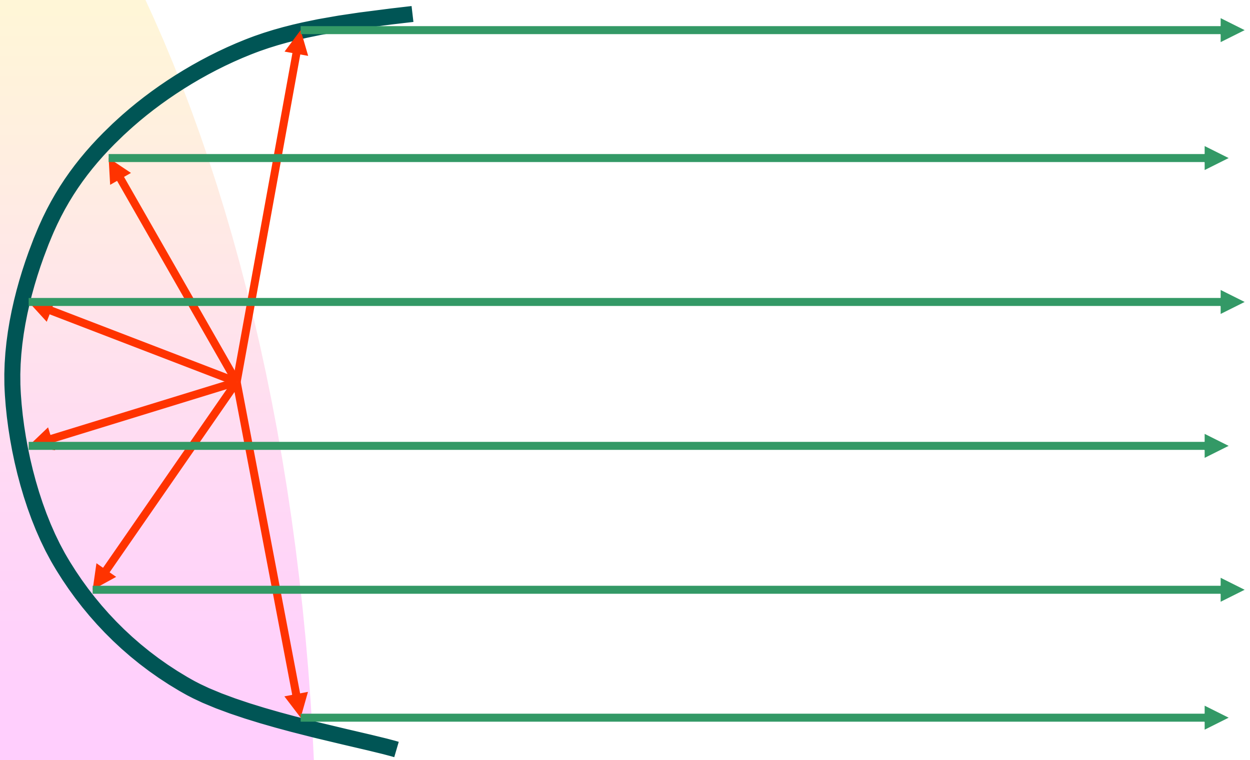
Reflection of sound waves: echo location





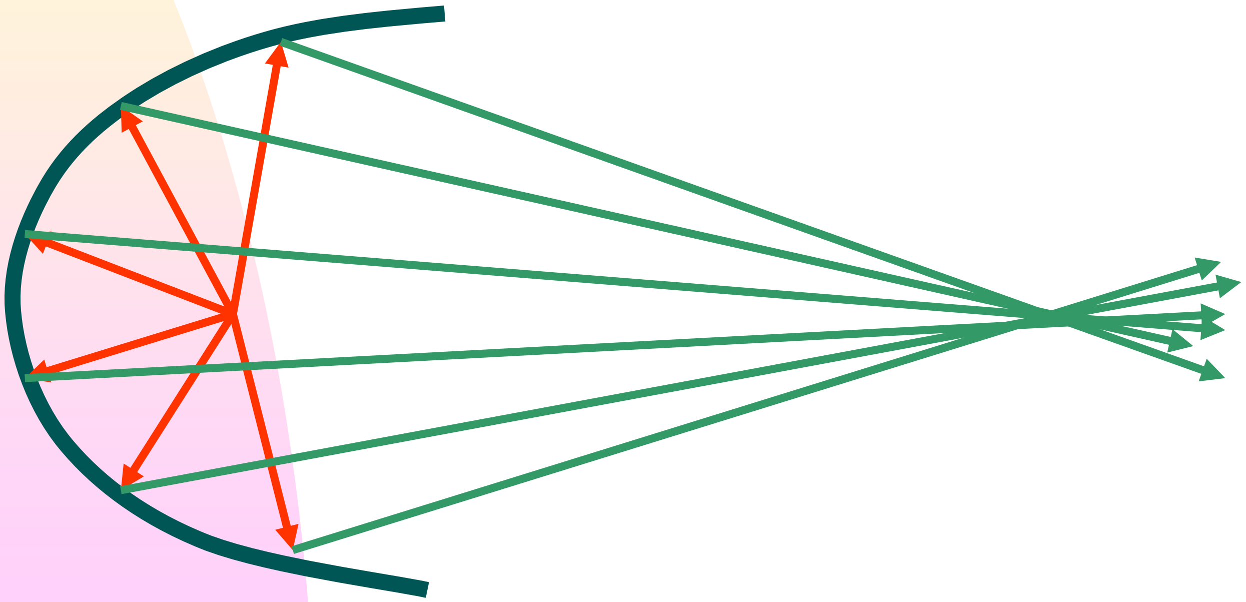
Reflection from Curved Surfaces

PARABOLIC REFLECTOR

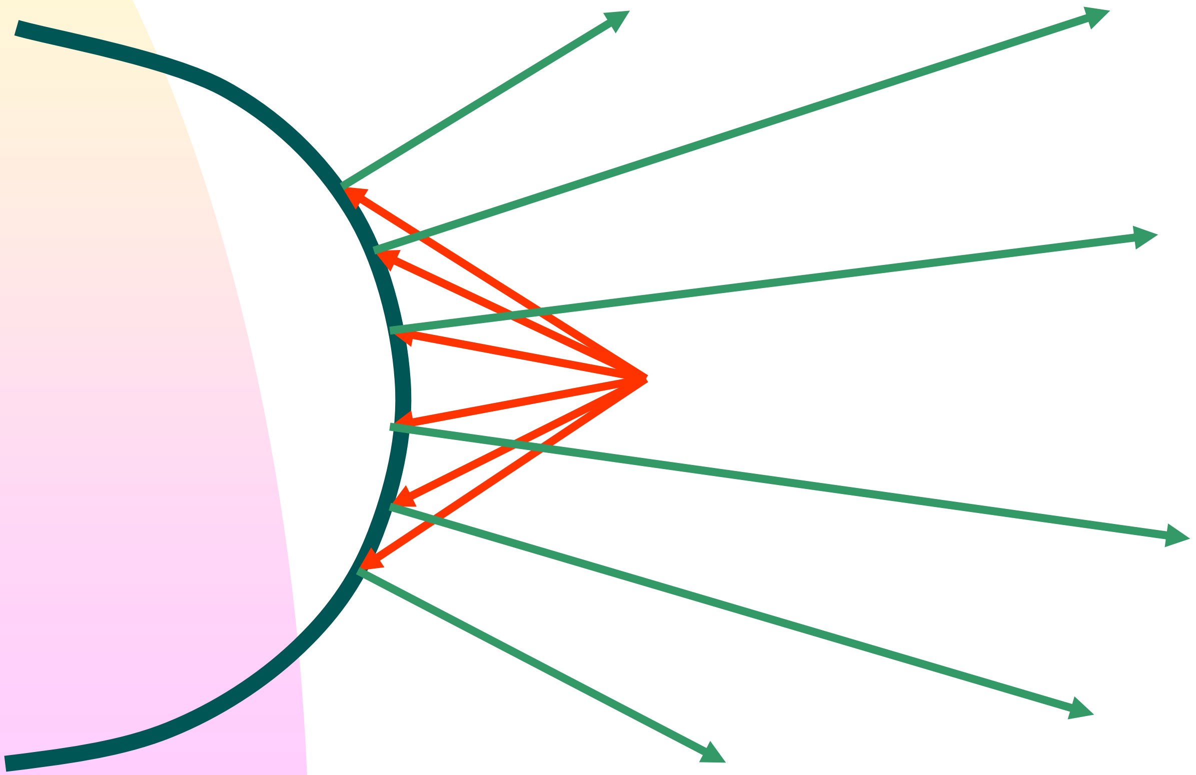


Reflection from Curved Surfaces

ELLIPSOIDAL REFLECTOR

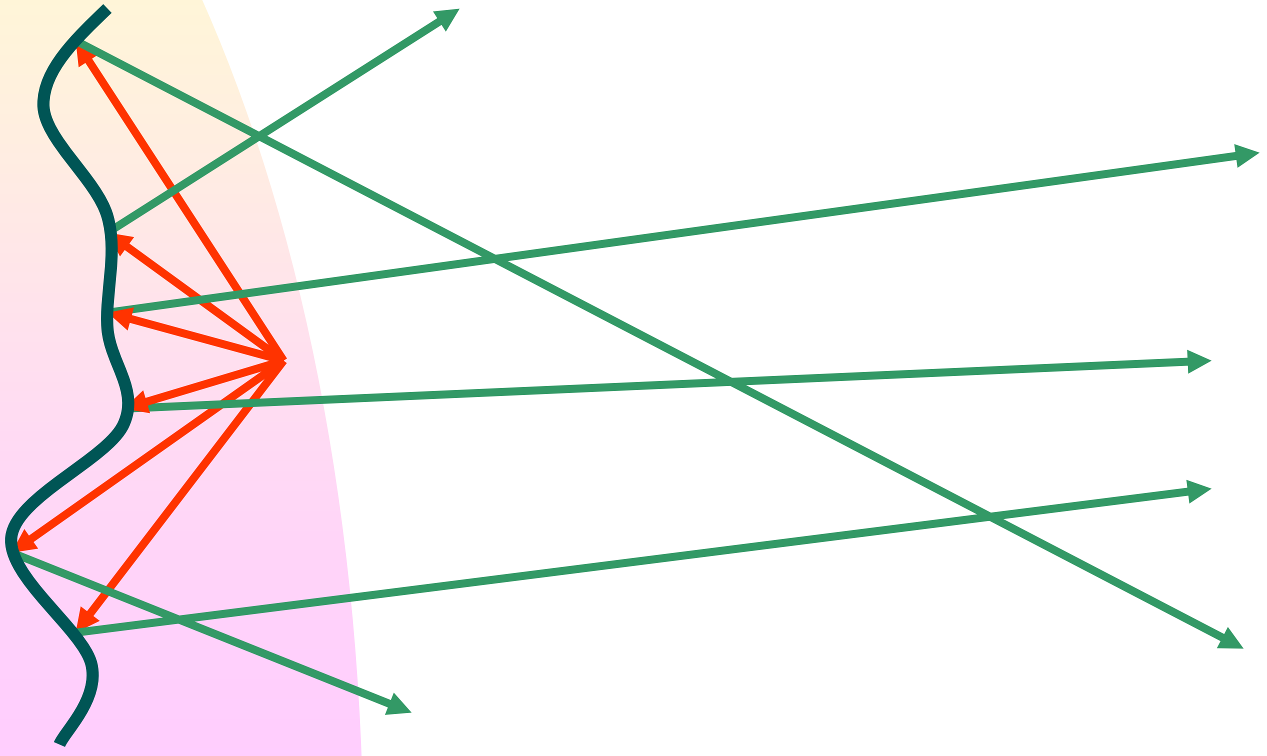


Reflection from Curved Surfaces



Diffuse Reflection

REFLECTION FROM A ROUGH SURFACE

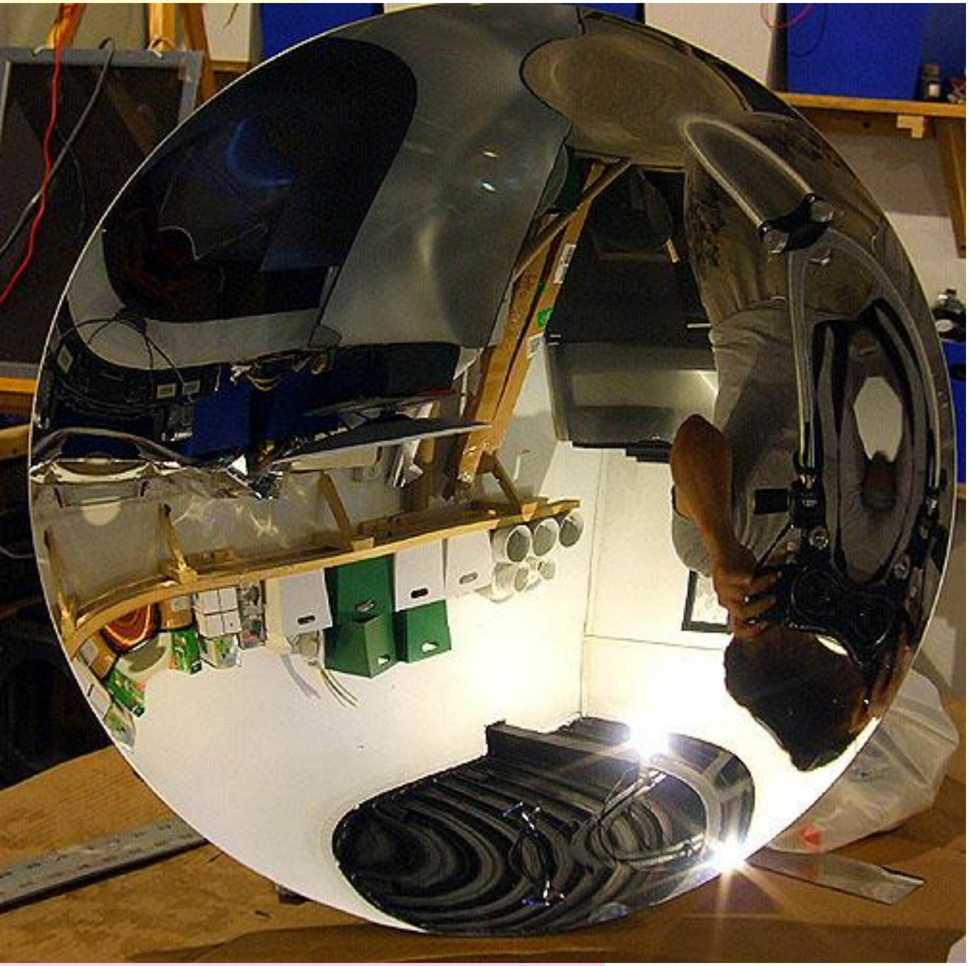


Reflection of light waves

← Plane mirror

Convex mirror

Reflection of light waves

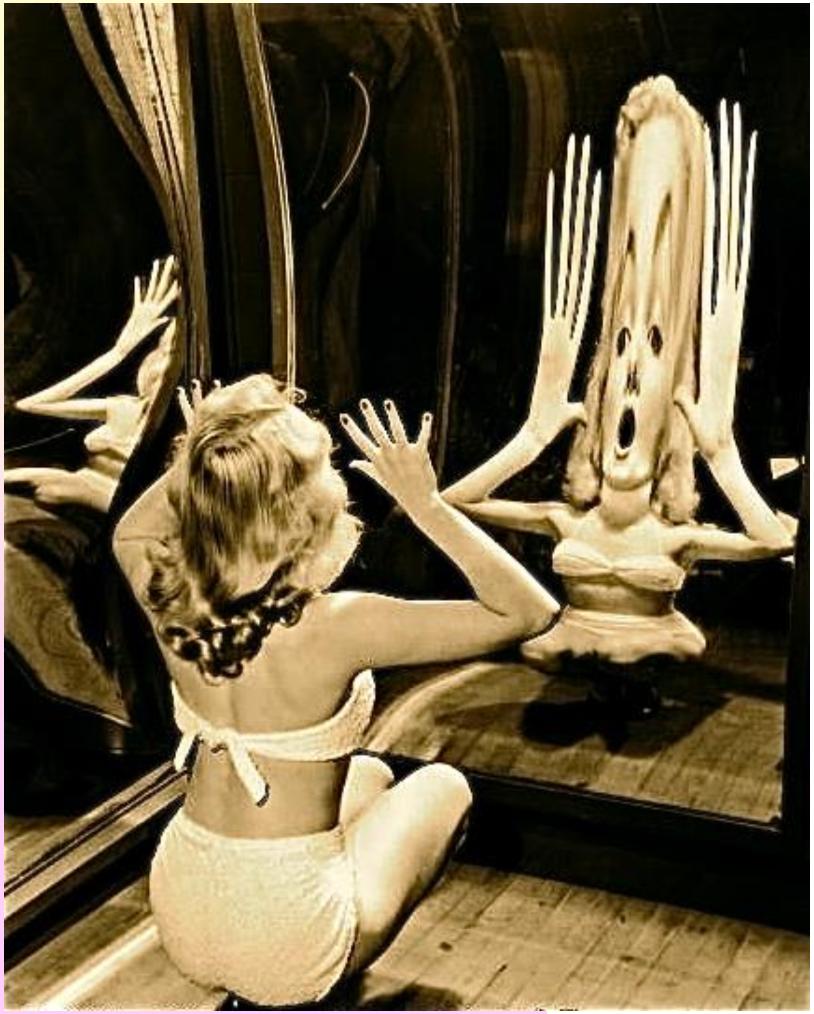


← *Concave mirror*

Interactive applet for ray tracing (FYI only)

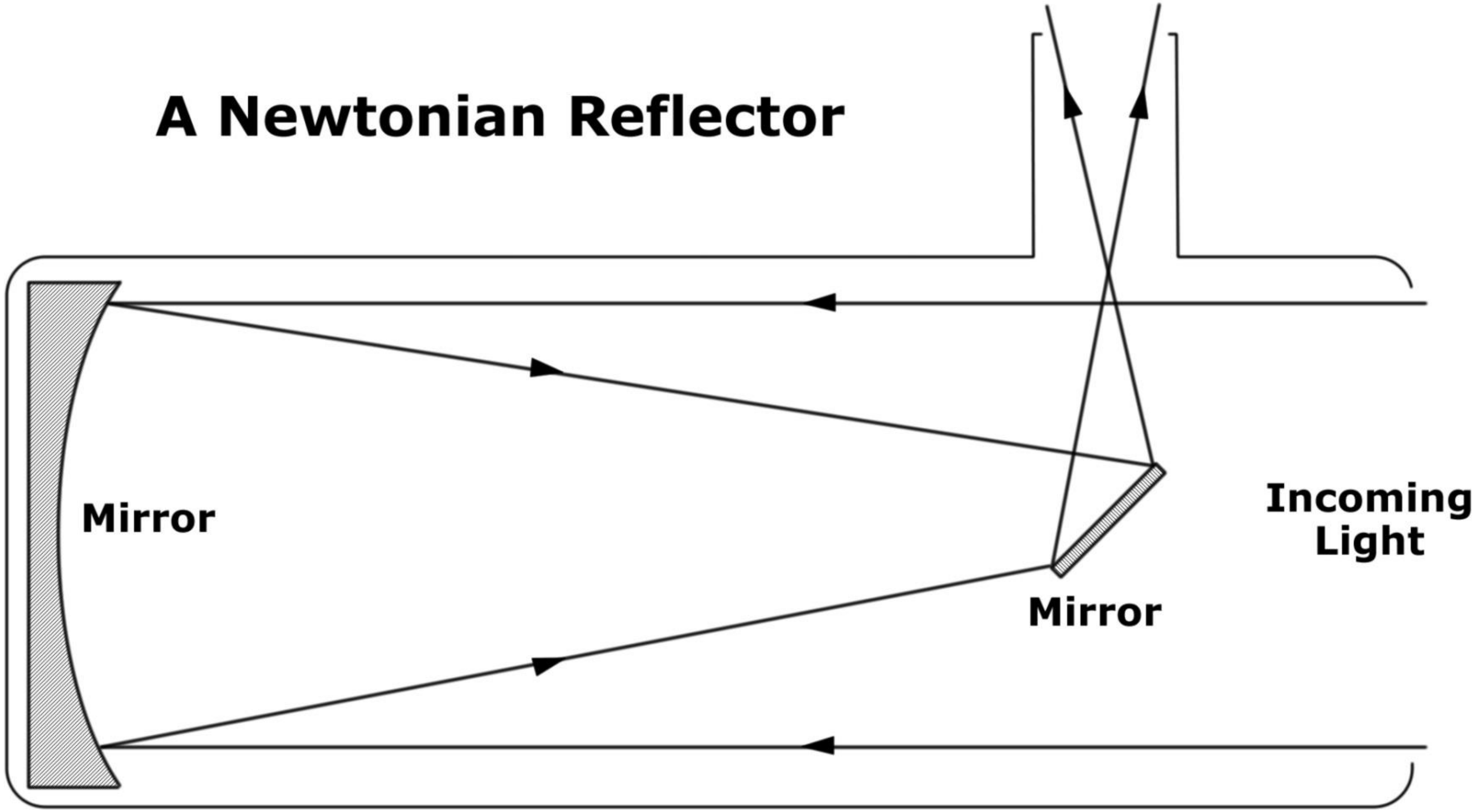
Parabolic reflector

Reflection of light waves



"Fun house" mirrors

Reflection: Focusing light waves in a reflecting telescope



Reflection: Focusing light waves

← solar furnace

Reflection: Focusing light waves

← solar furnace

ARCHIMEDES

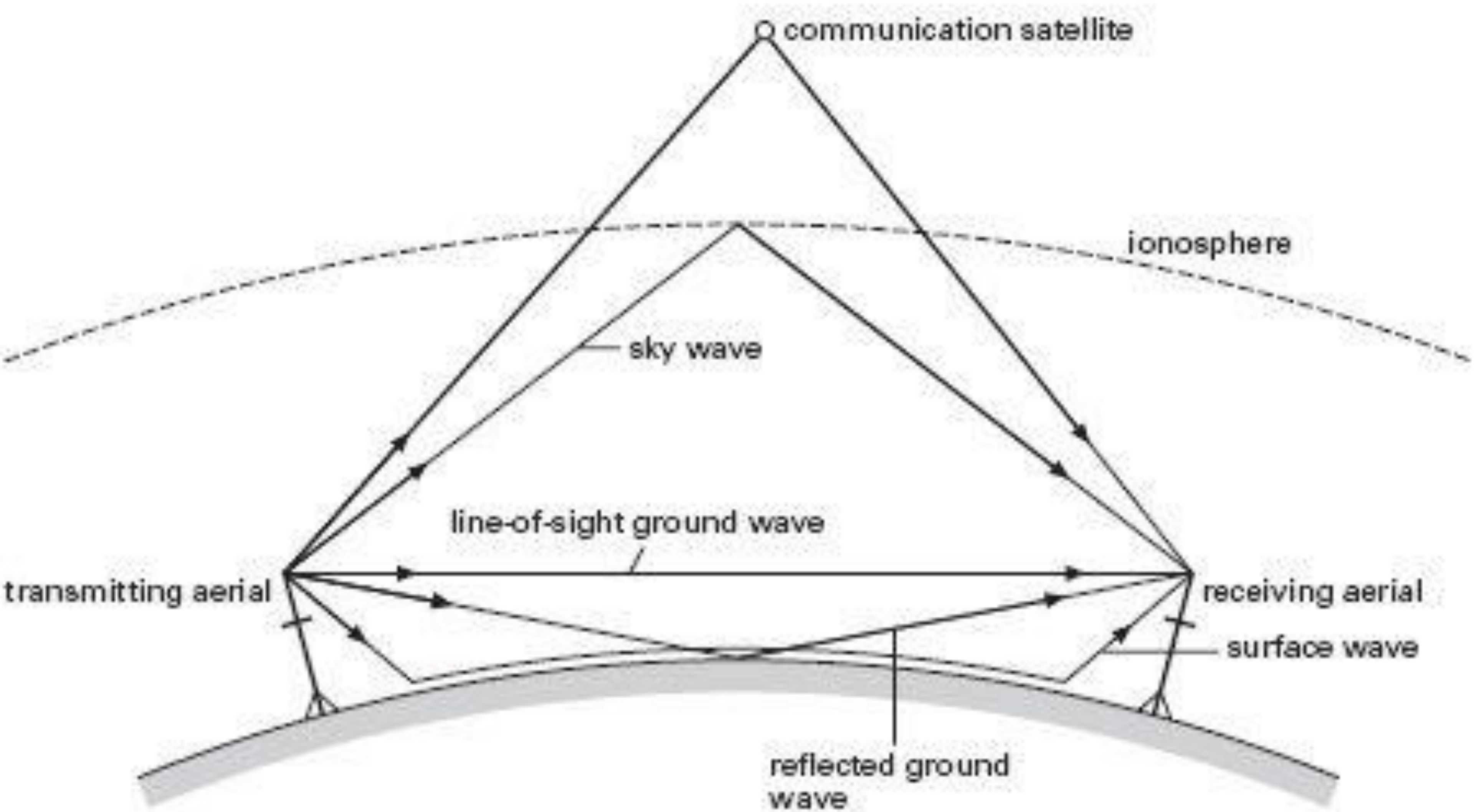
Mirror to focus light waves …

… for military purposes

Reflection: Focusing microwaves

Reflection: Focusing radio waves

Reflection of radio waves



Reflection of sound waves:
Sound focusing at the Cathedral of Agrigento in Sicily

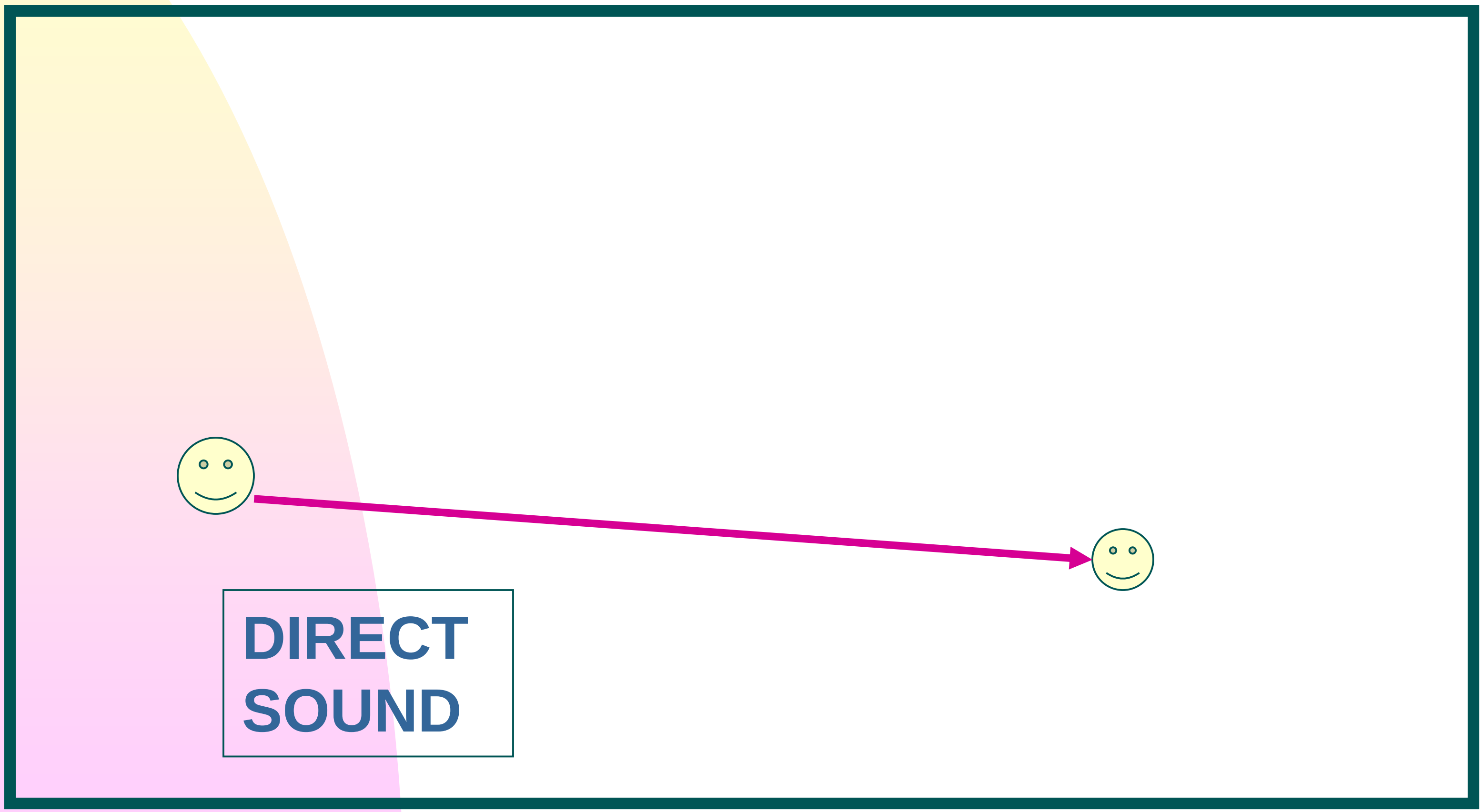
Reflection of sound waves:
Sound focusing in domes (Whispering galleries)

← St. Paul's Cathedral (London)

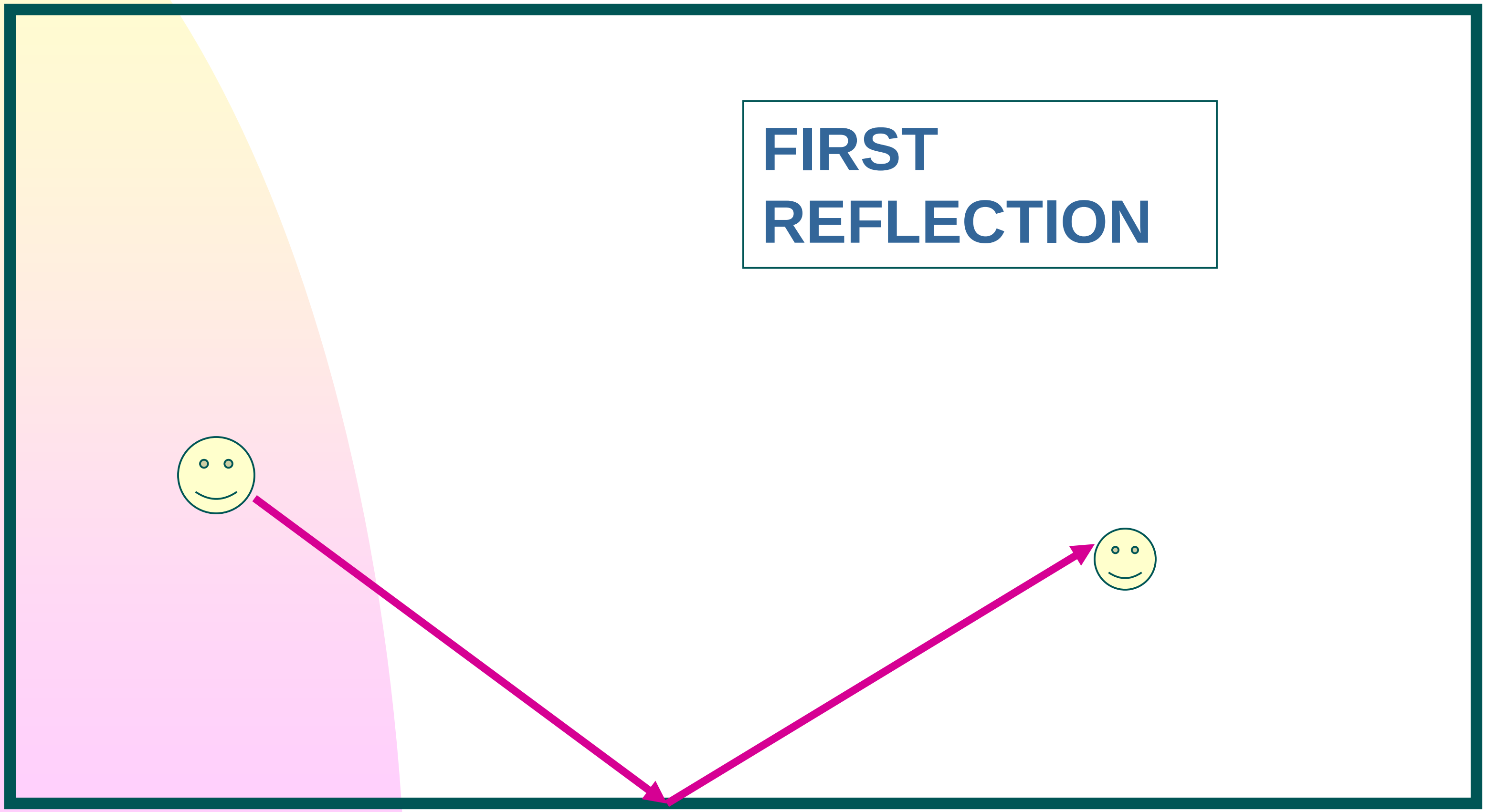
U.S. Capitol Building→ (Washington D.C.)

Reflection of sound waves: Focusing

Reflection and Room Acoustics



Reflection and Room Acoustics



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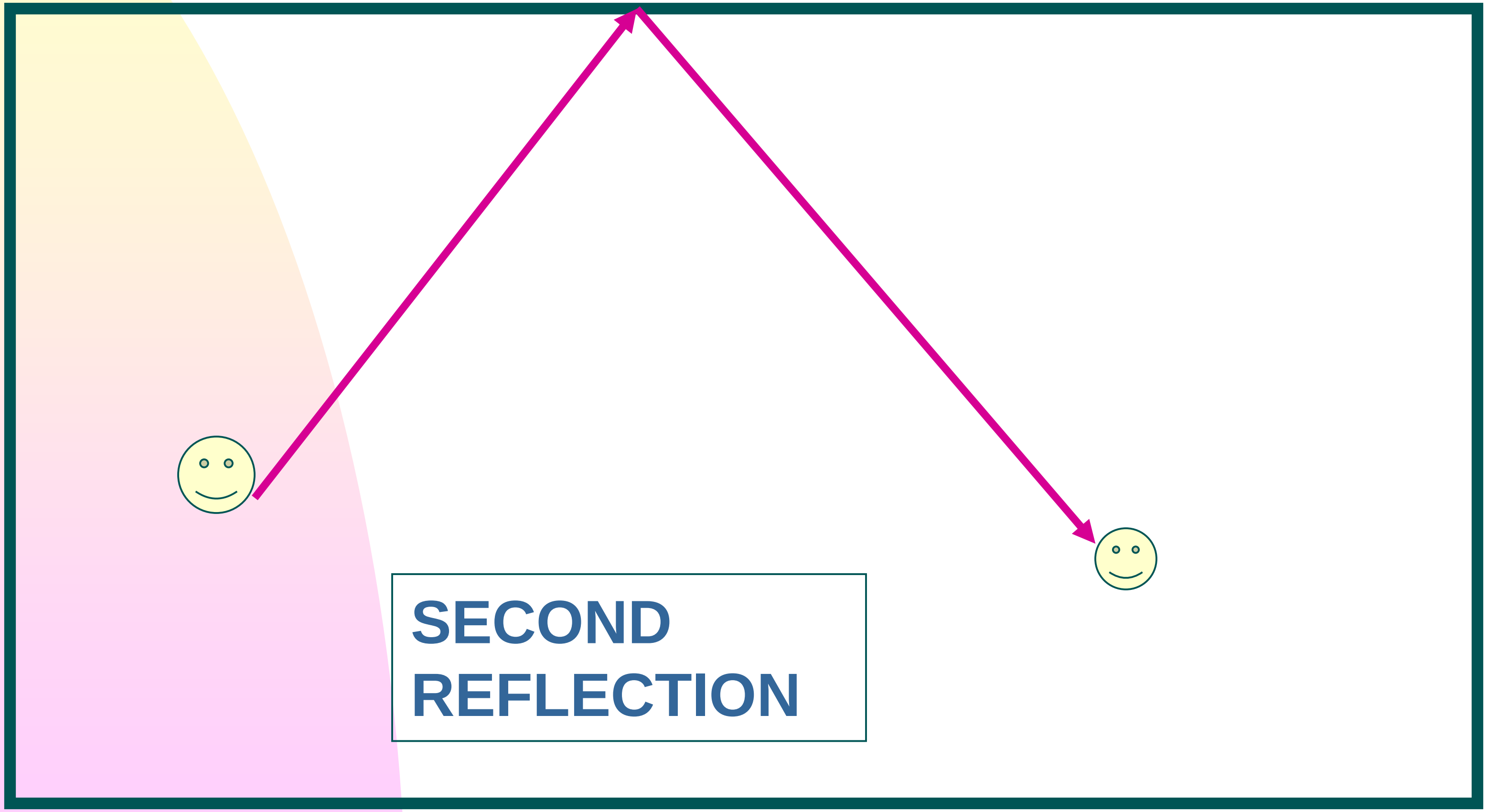
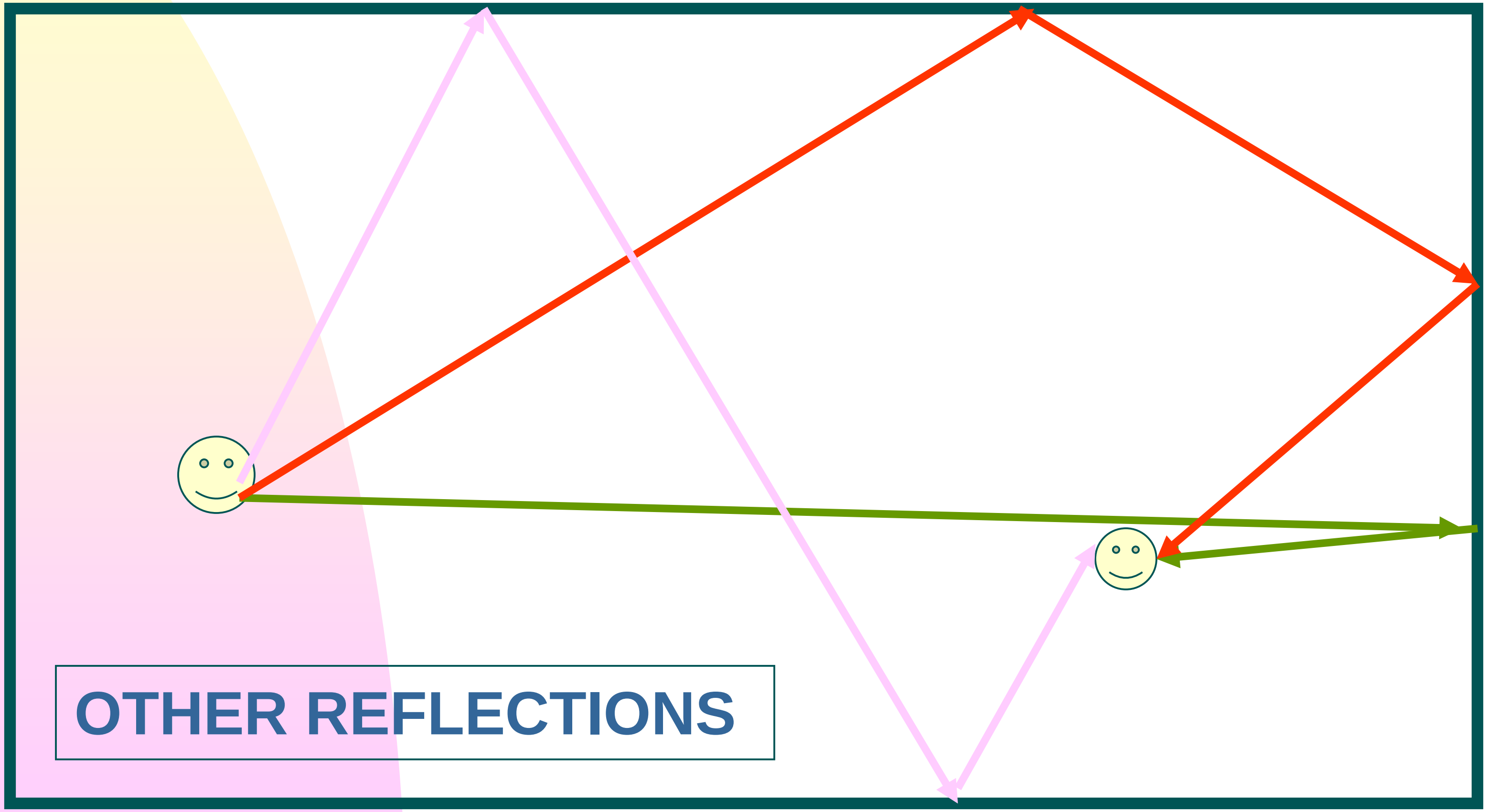


Reflection and Room Acoustics



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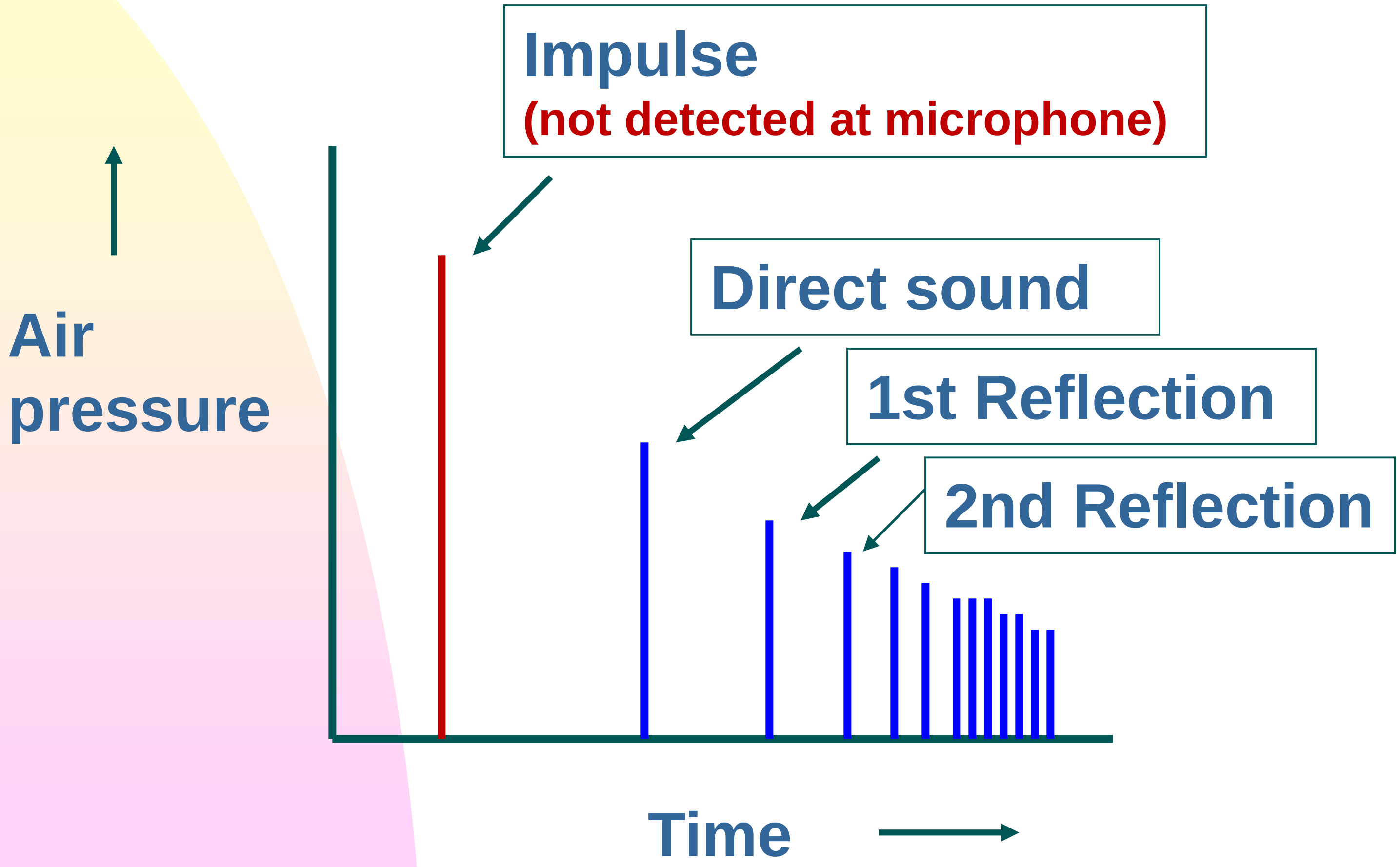
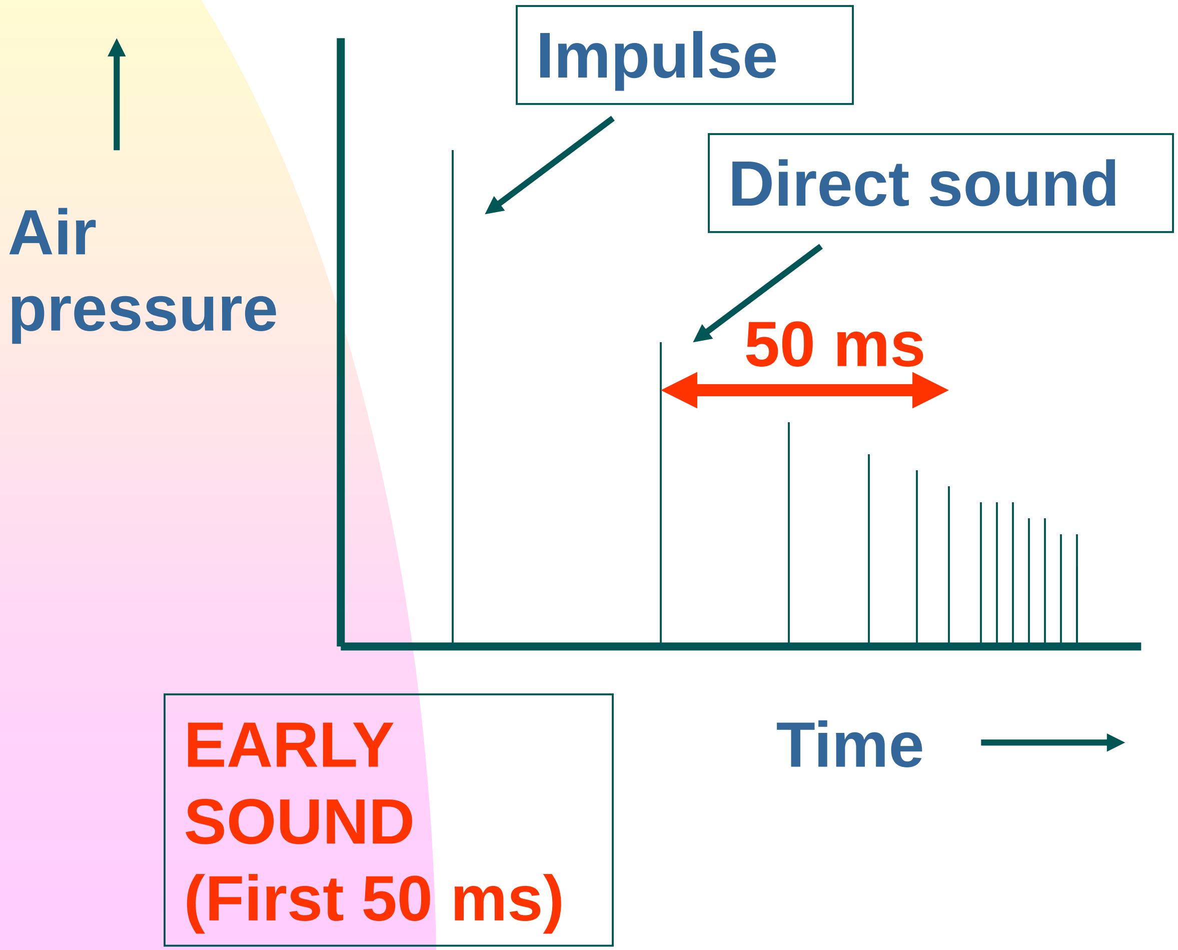
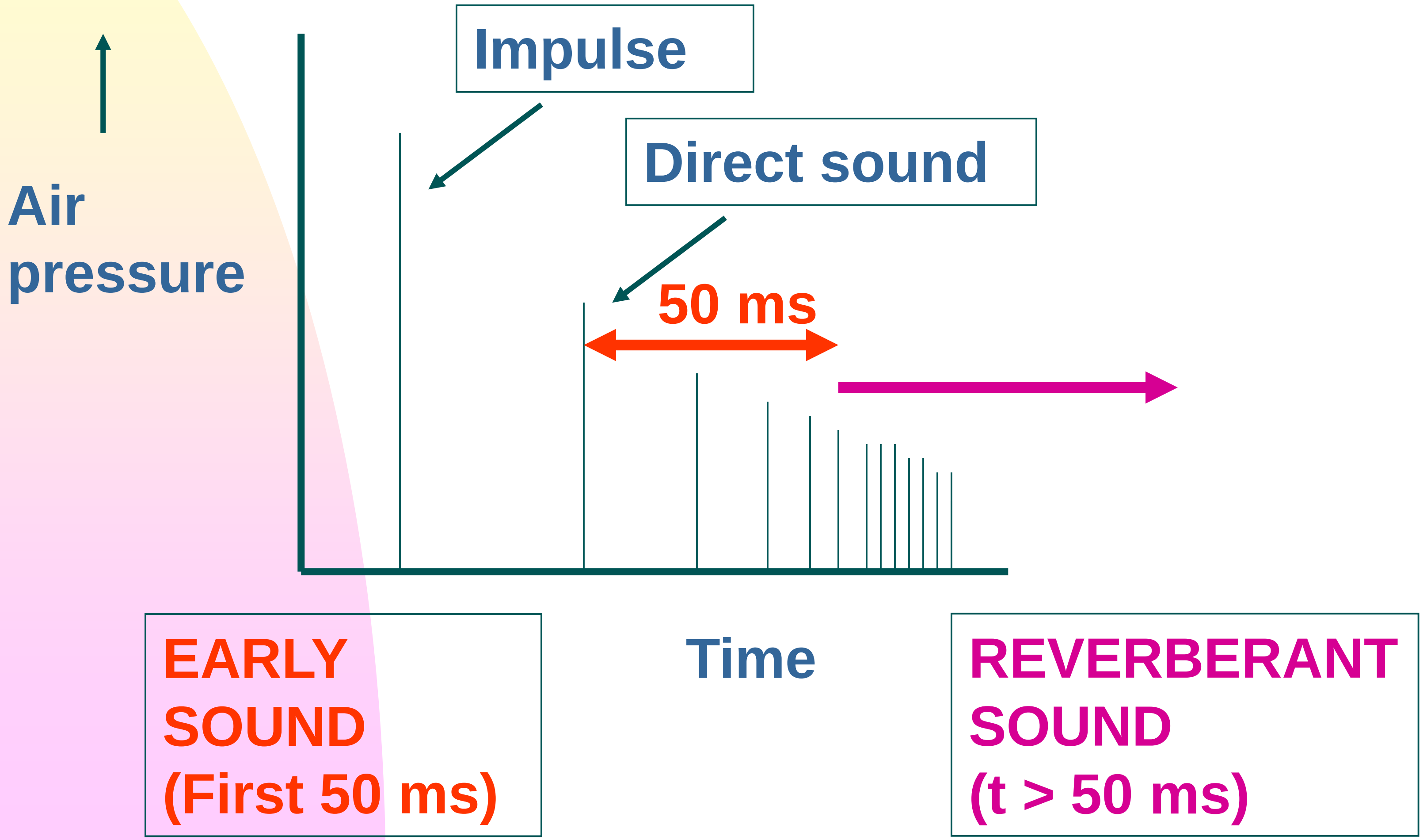


Reflection and Room Acoustics



Reflection and Room Acoustics



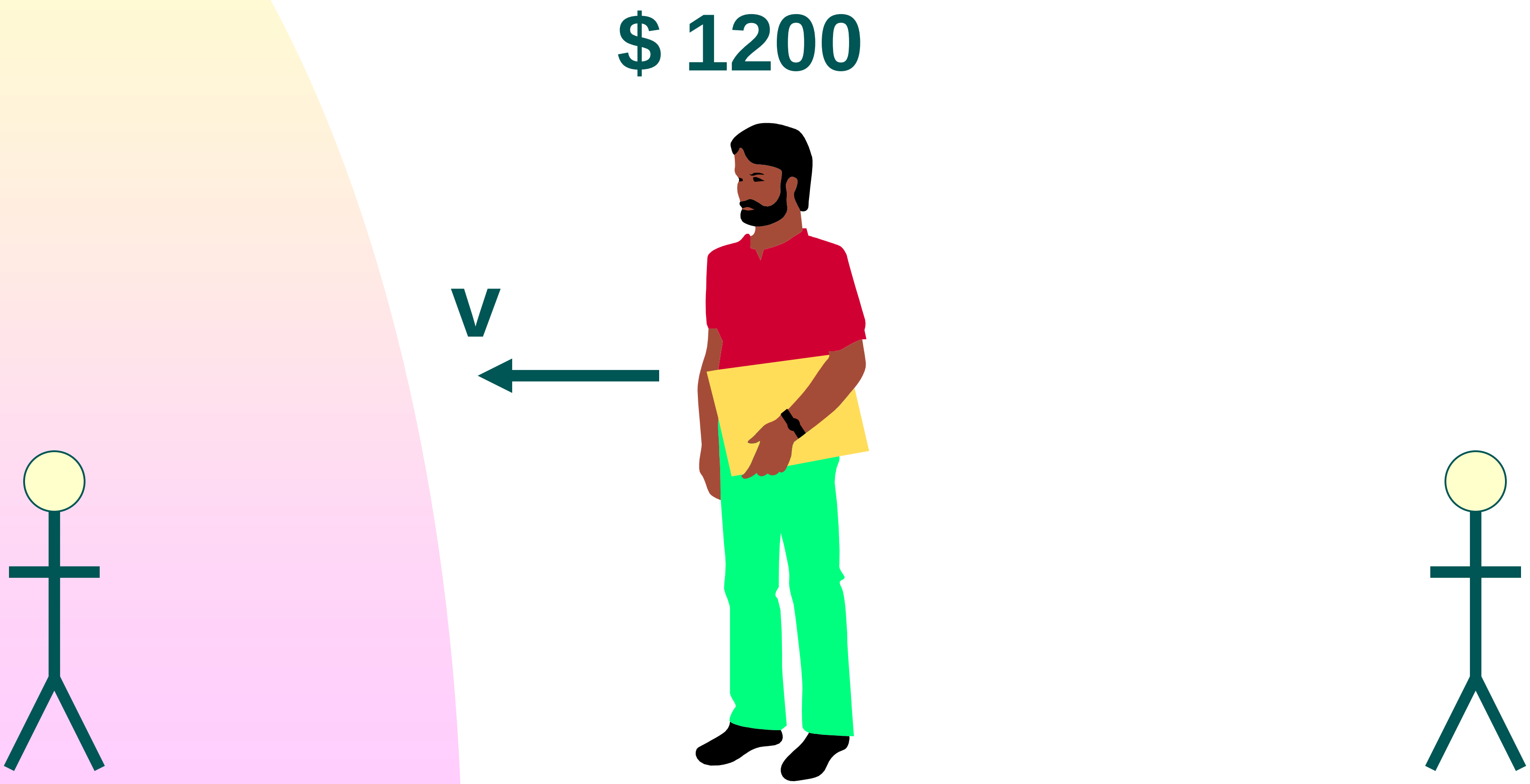
Reverberation Time

- REVERBERATION TIME is the time required for the sound intensity in the auditorium to decrease to 1 millionth of its original magnitude.

  [This is equivalent to the sound intensity level decreasing by 60 dB.]

Reverberation Time

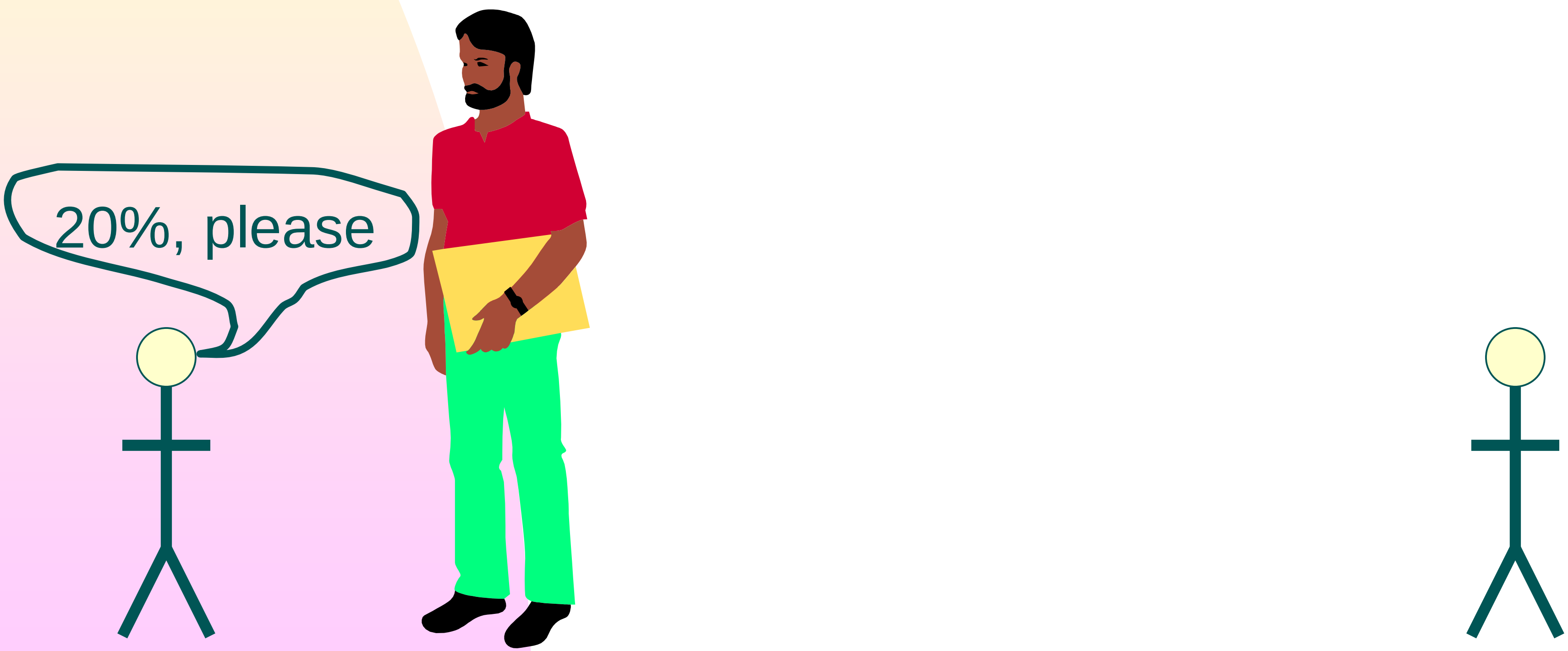
- Analogy ...



Reverberation Time

- Analogy ...

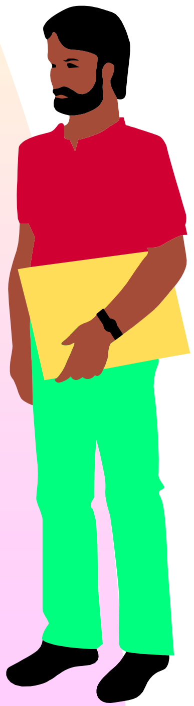
$ 1200

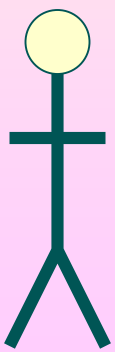


Reverberation Time

- Analogy ...

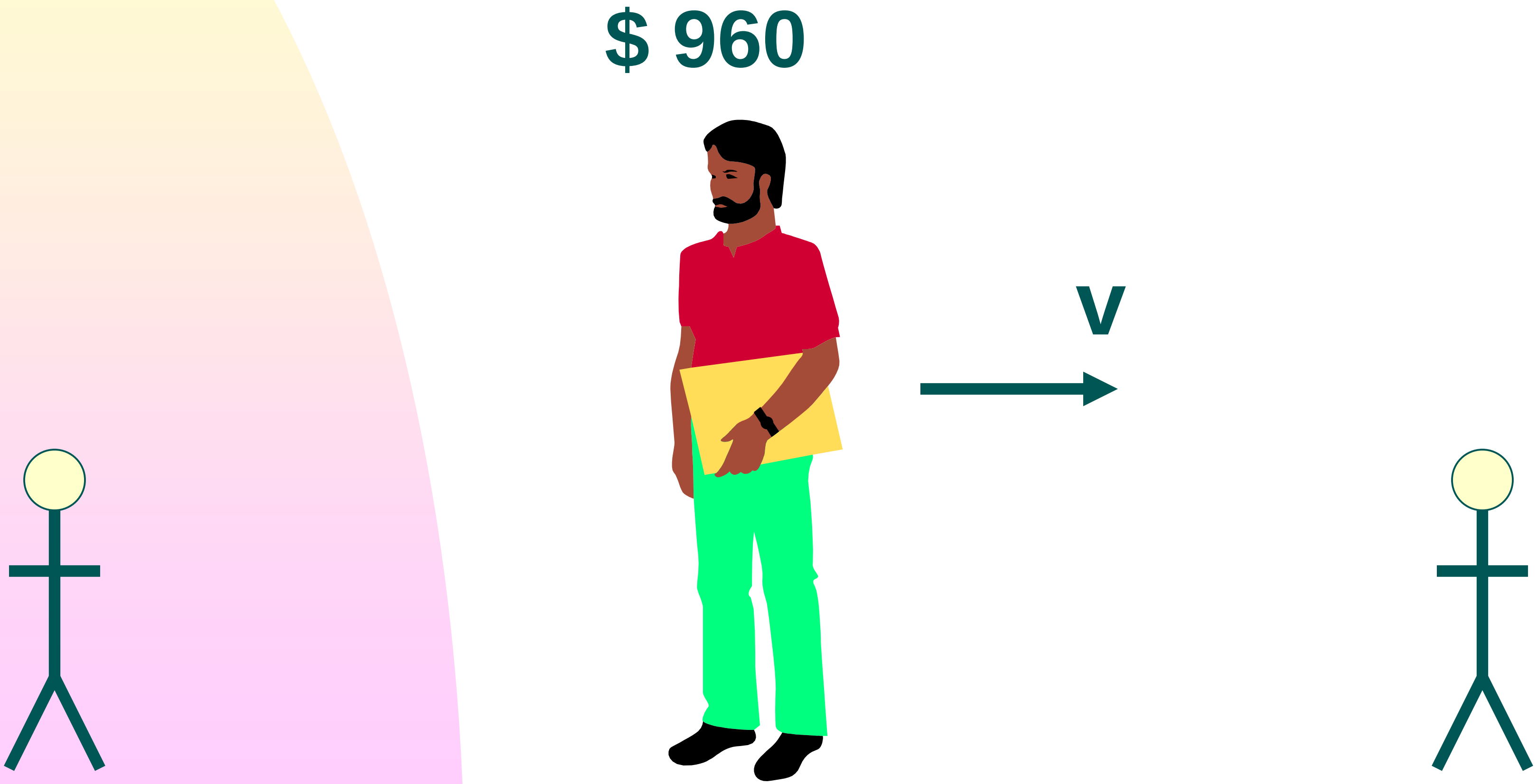
$ 960





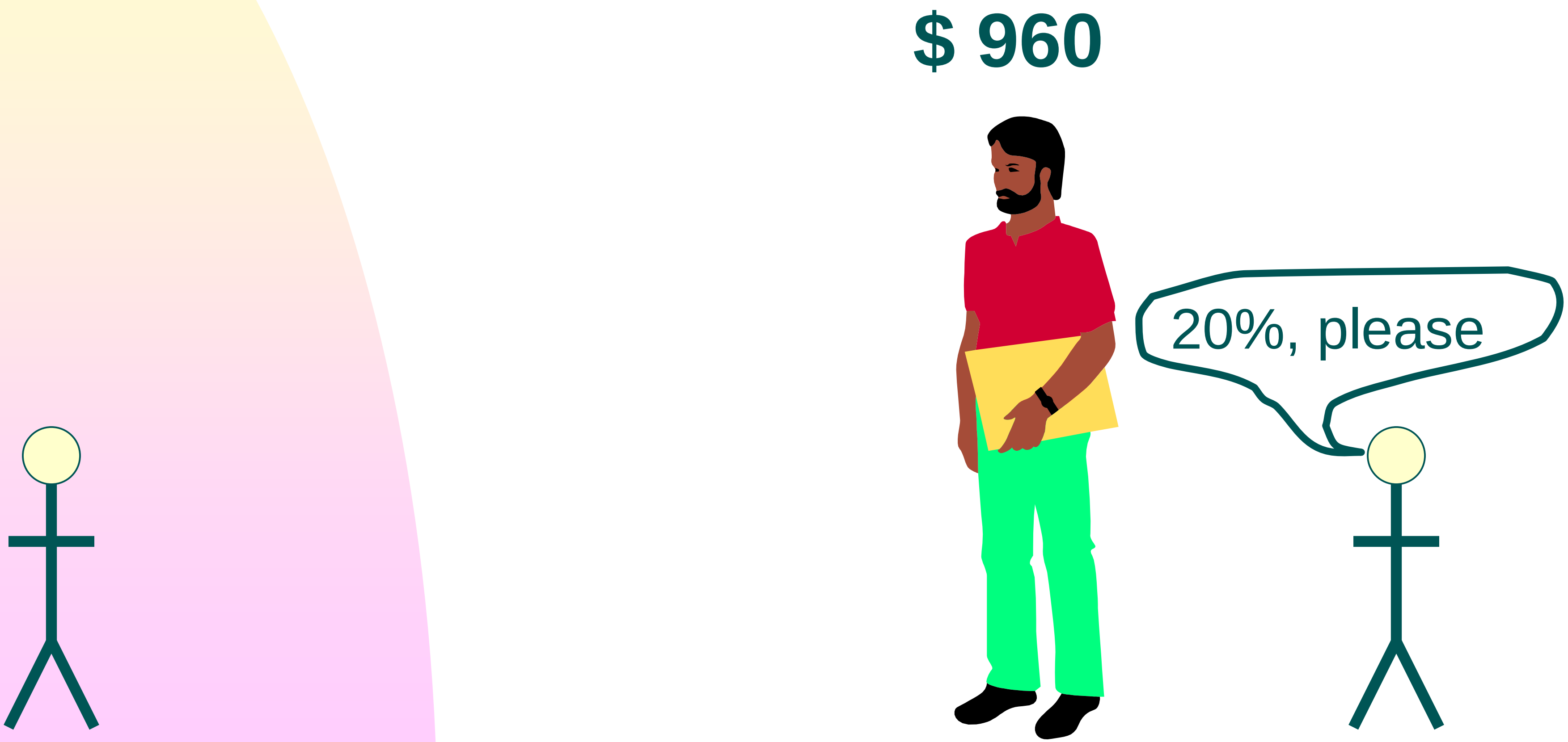
Reverberation Time

- Analogy ...



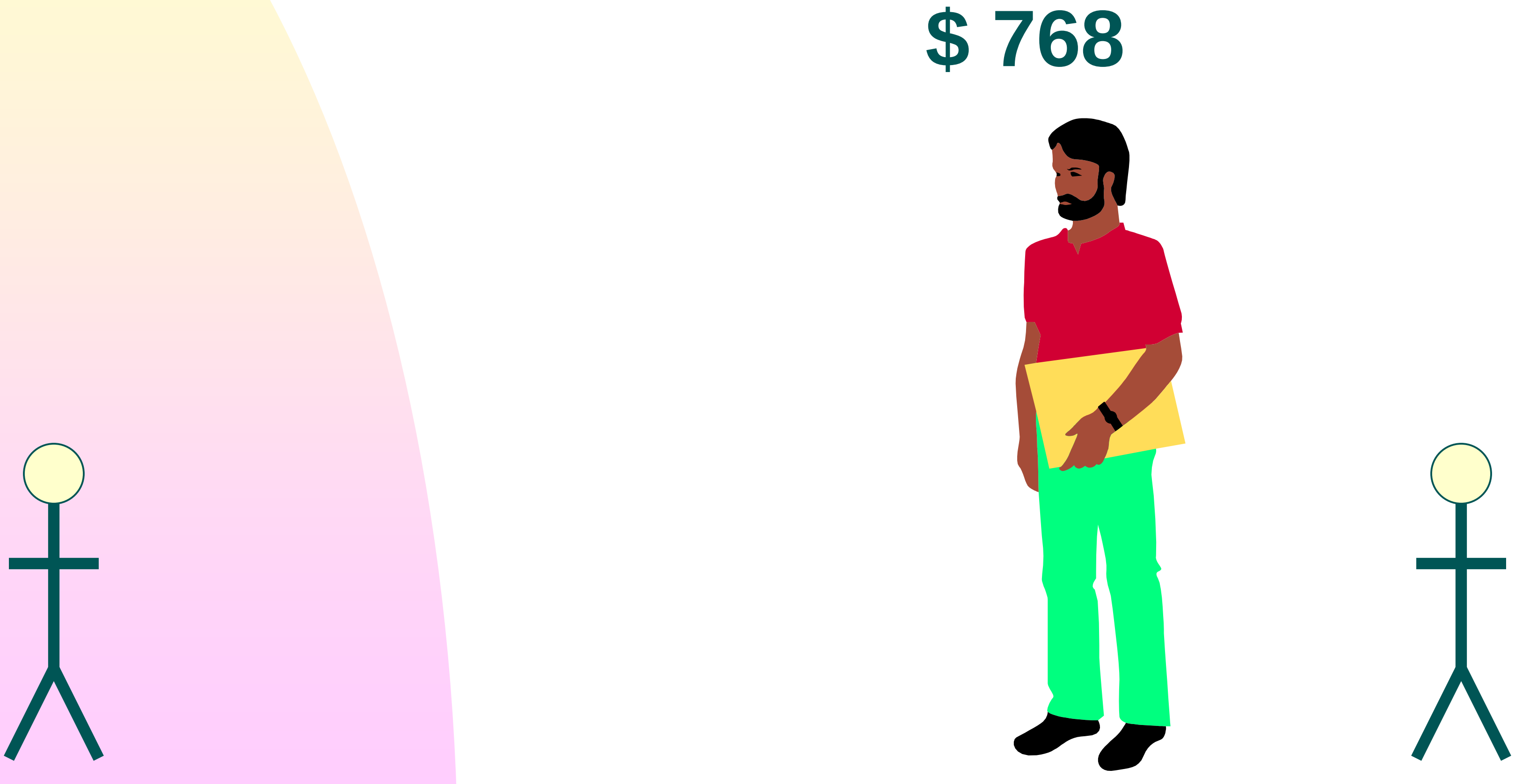
Reverberation Time

- Analogy ...



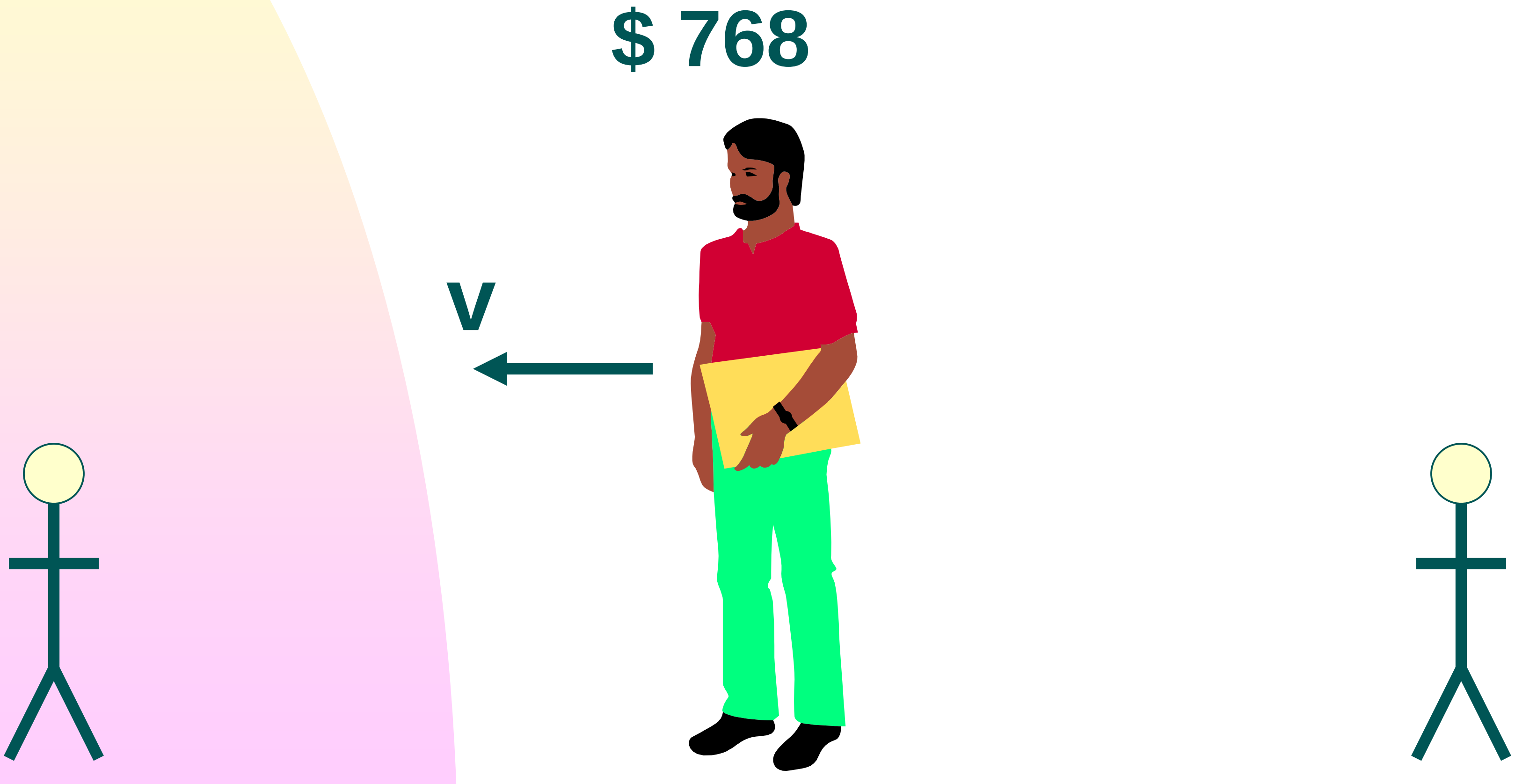
Reverberation Time

- Analogy ...



Reverberation Time

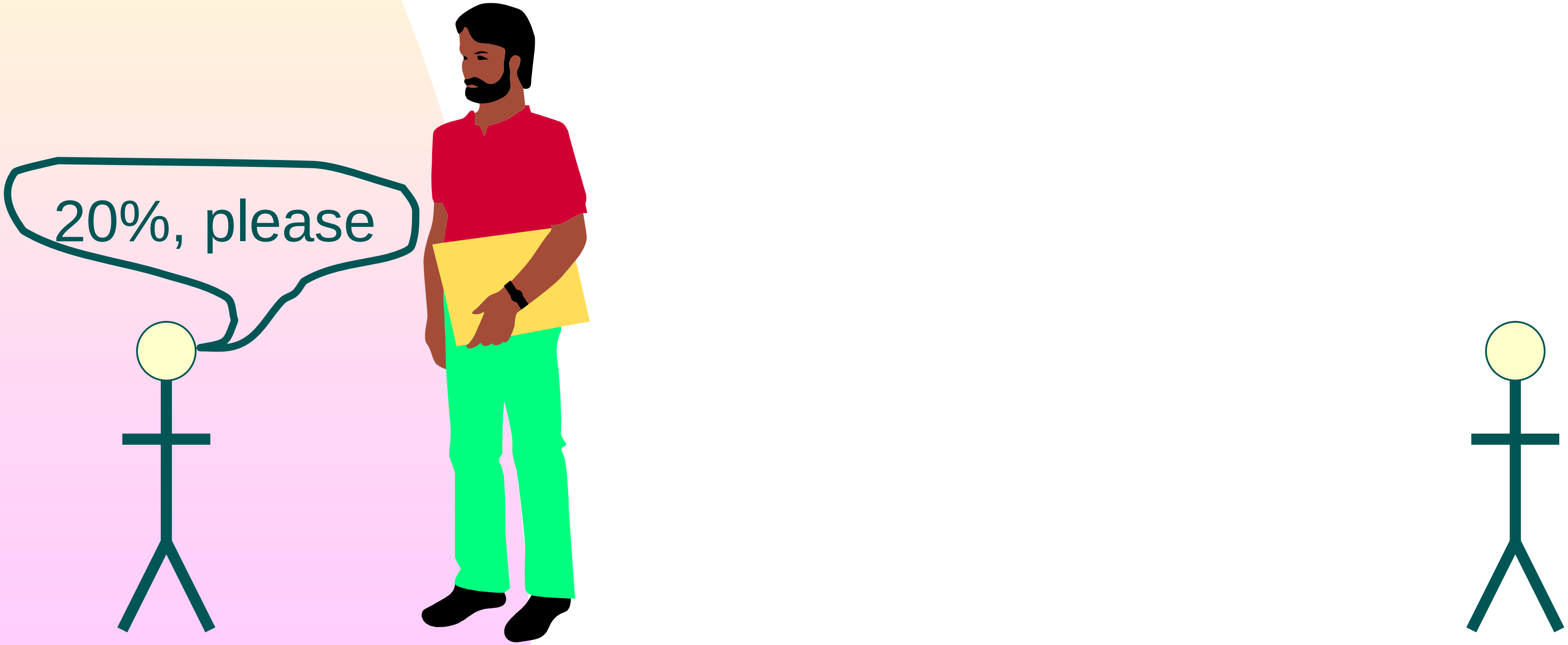
- Analogy ...



Reverberation Time

- Analogy ...

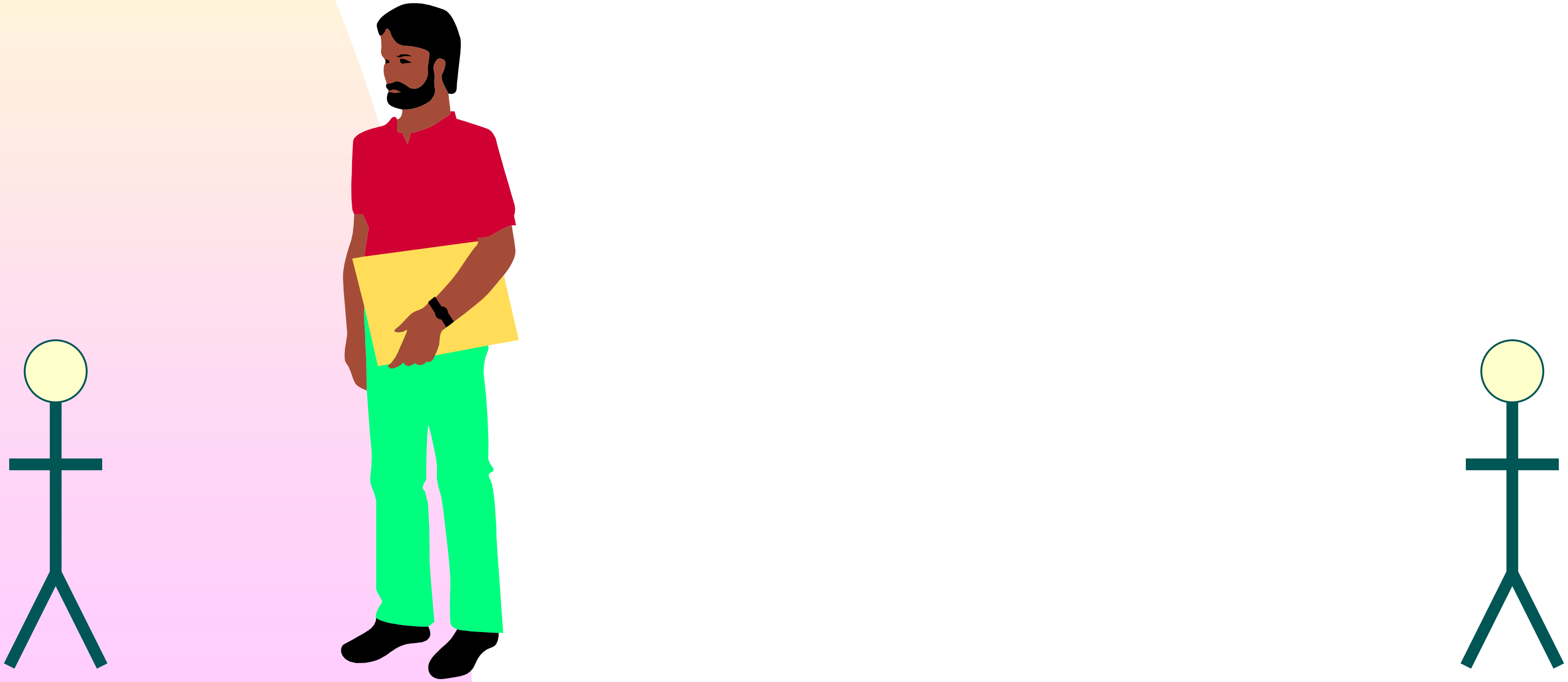
$ 768



Reverberation Time

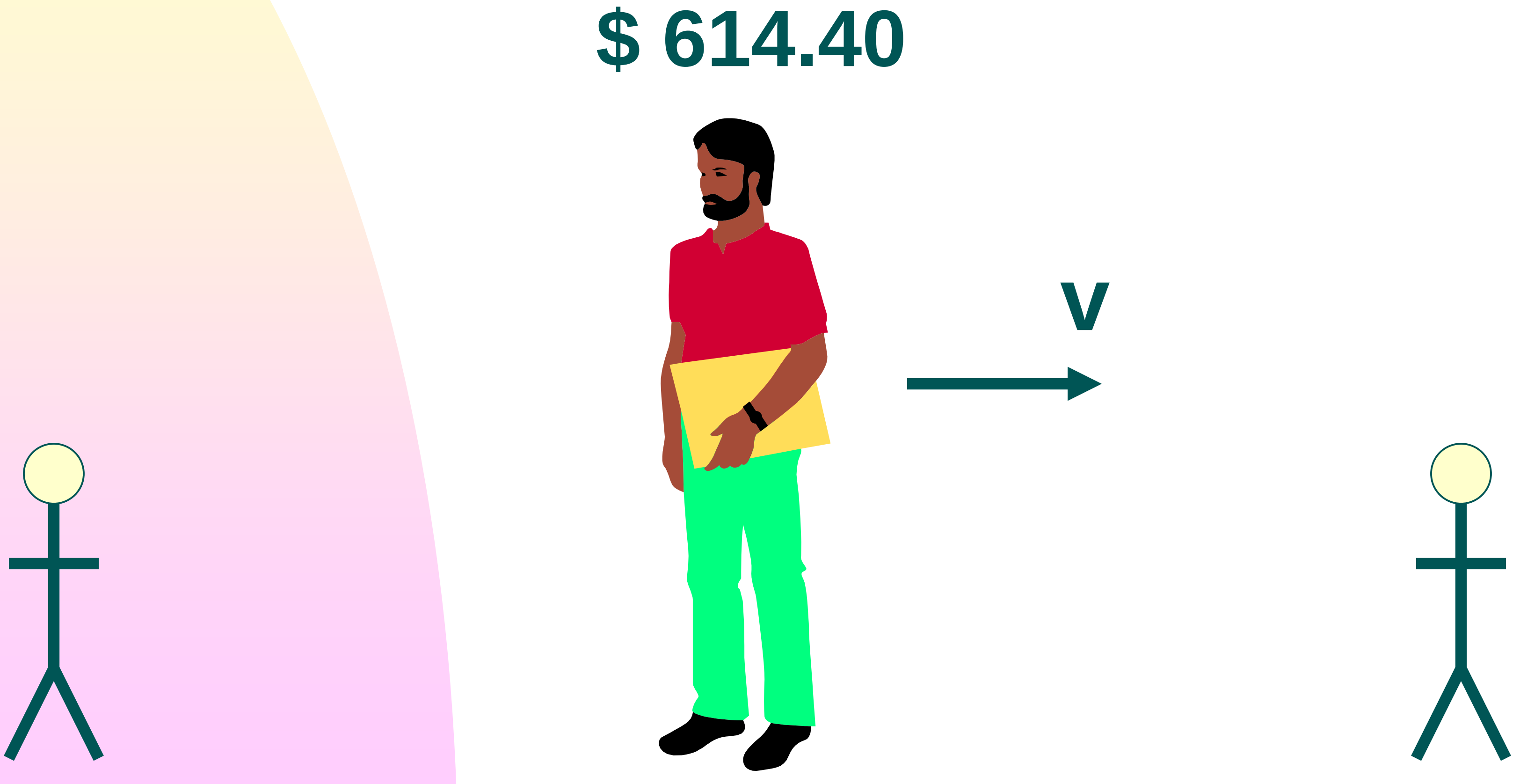
- Analogy ...

$ 614.40



Reverberation Time

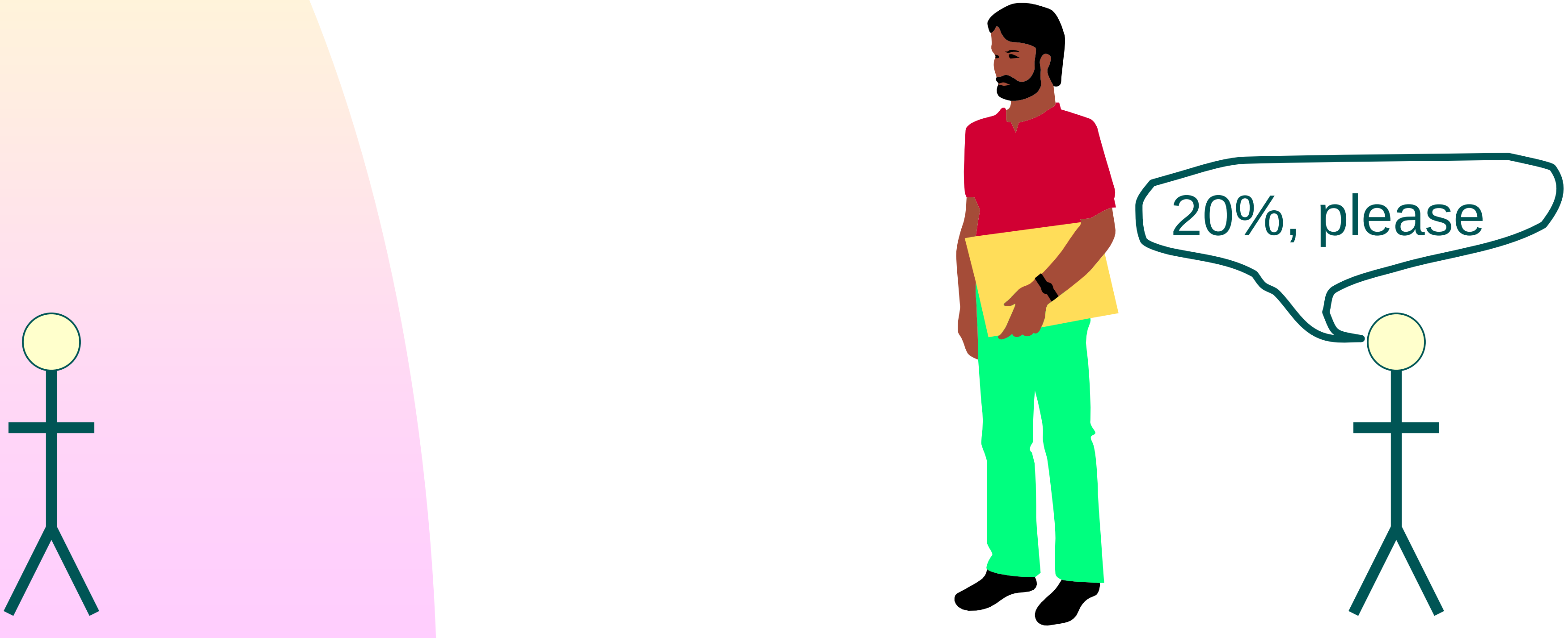
- Analogy ...



Reverberation Time

- Analogy ...

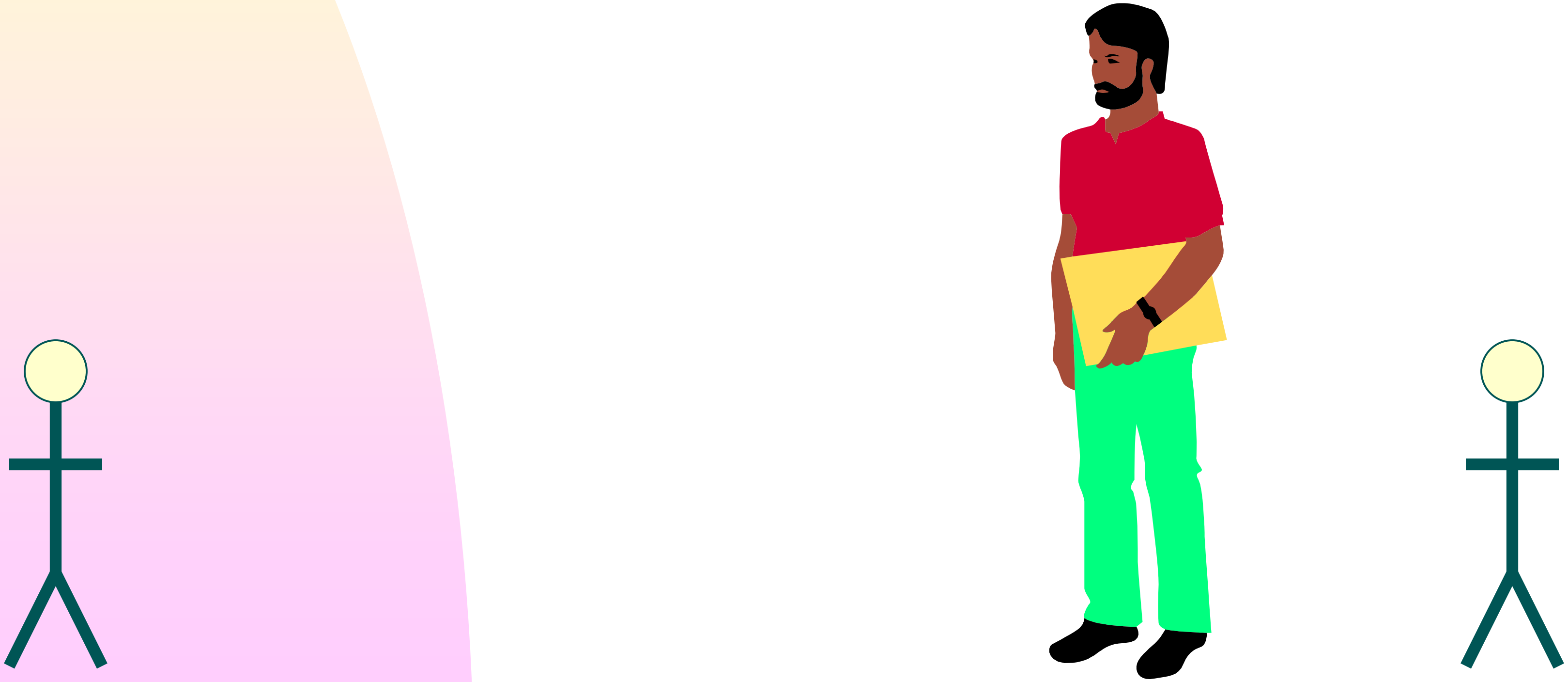
$ 614.40



Reverberation Time

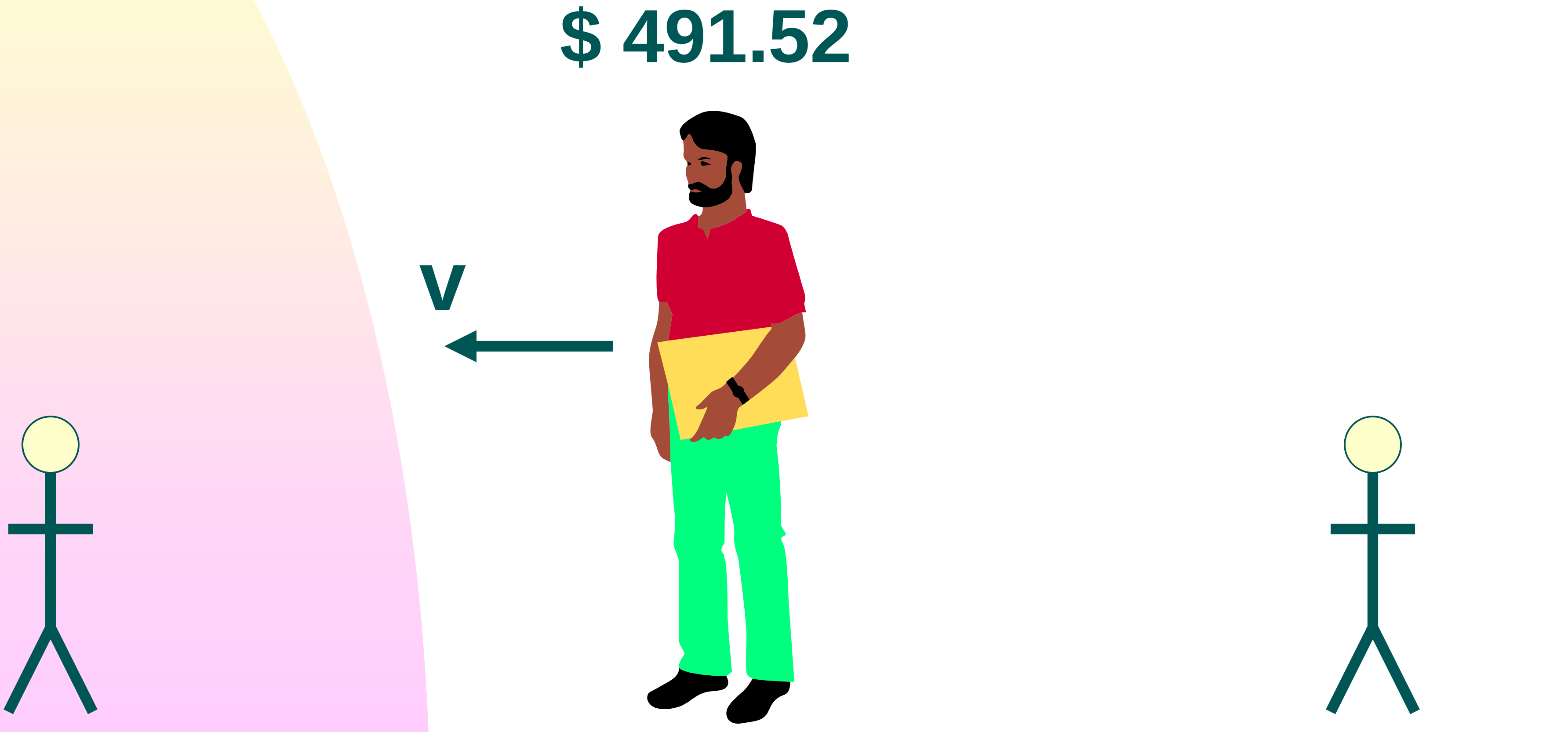
- Analogy ...

$ 491.52



Reverberation Time

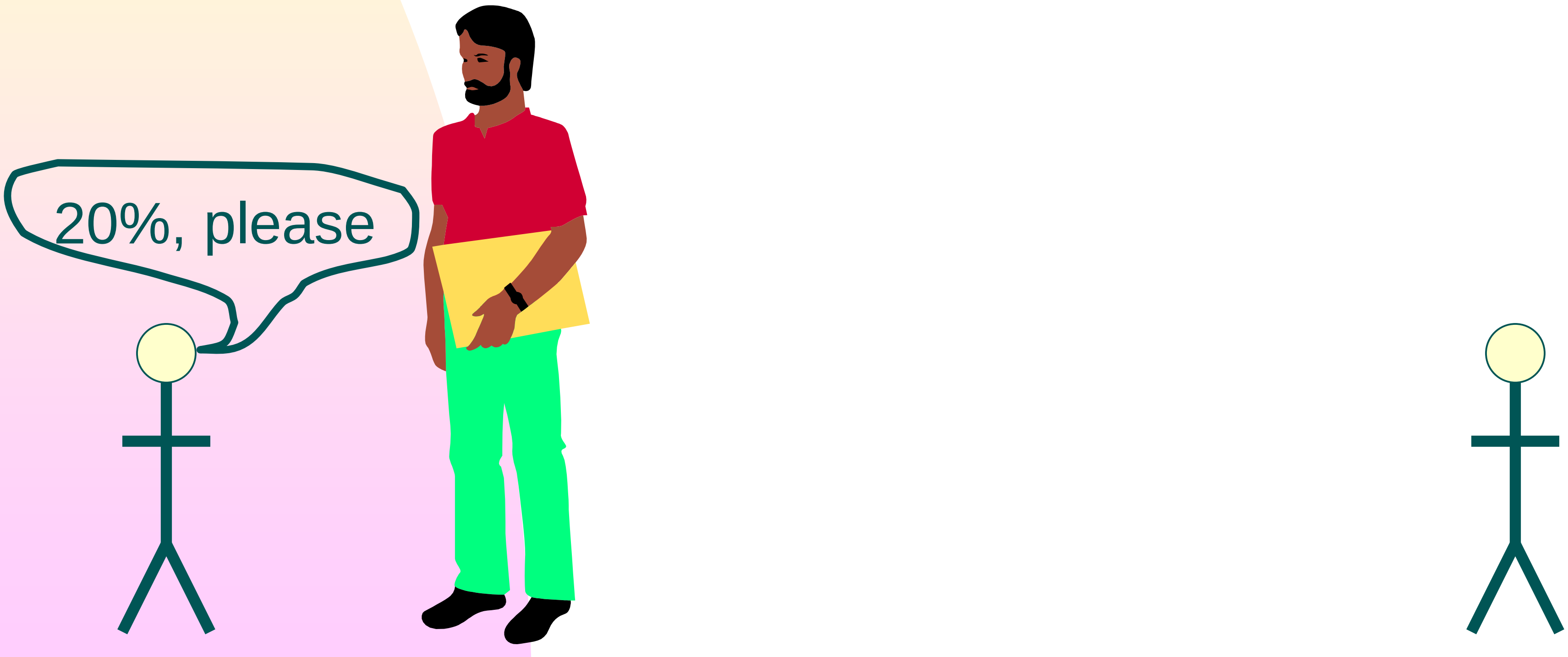
- Analogy ...



Reverberation Time

- Analogy ...

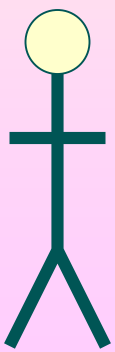
$ 491.52

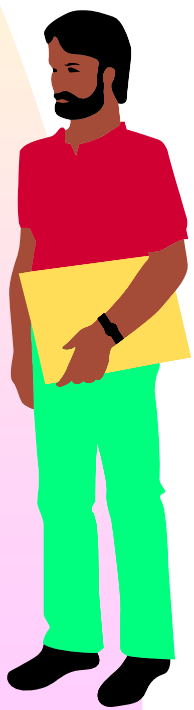


Reverberation Time

- Analogy ...

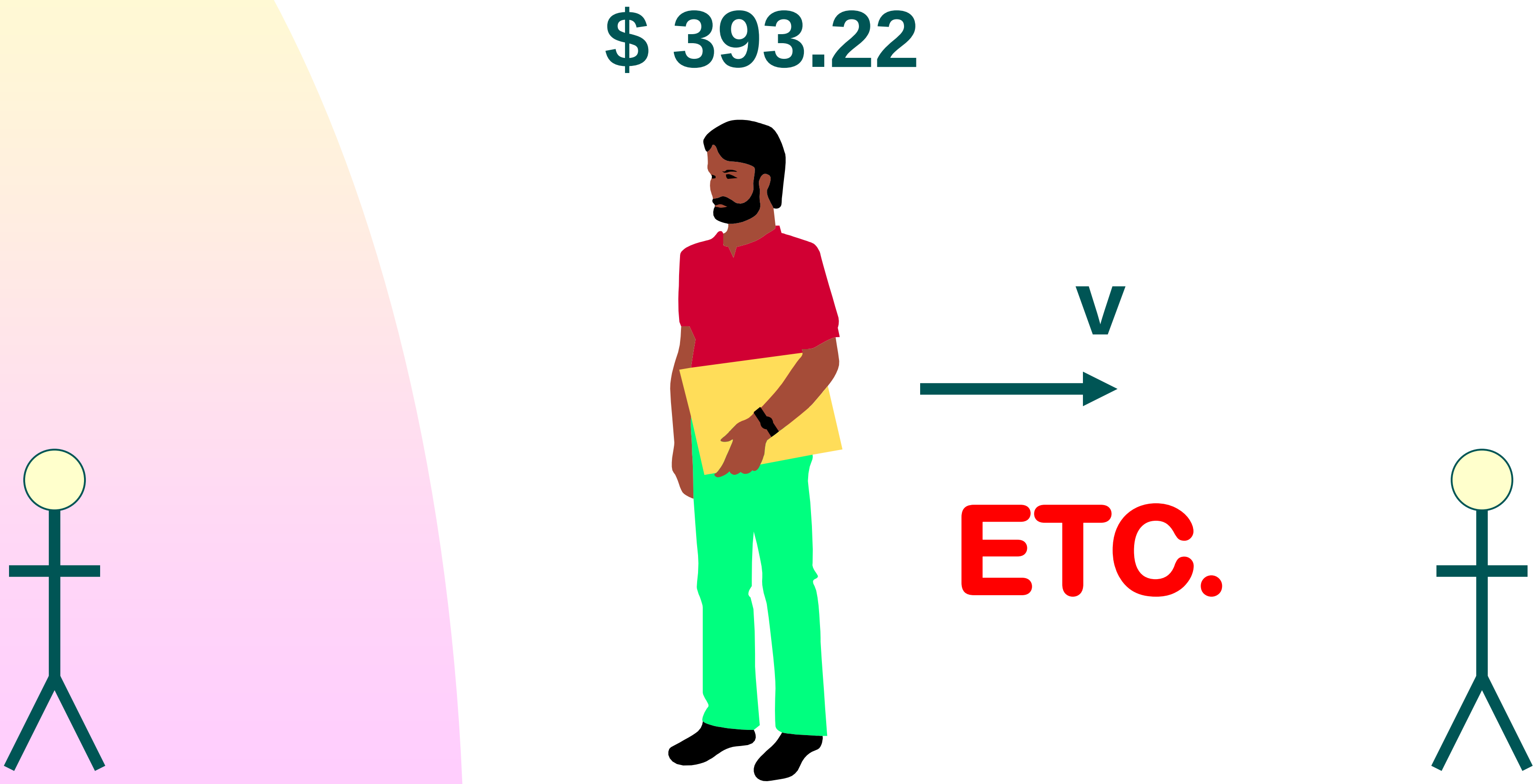
$ 393.22





Reverberation Time

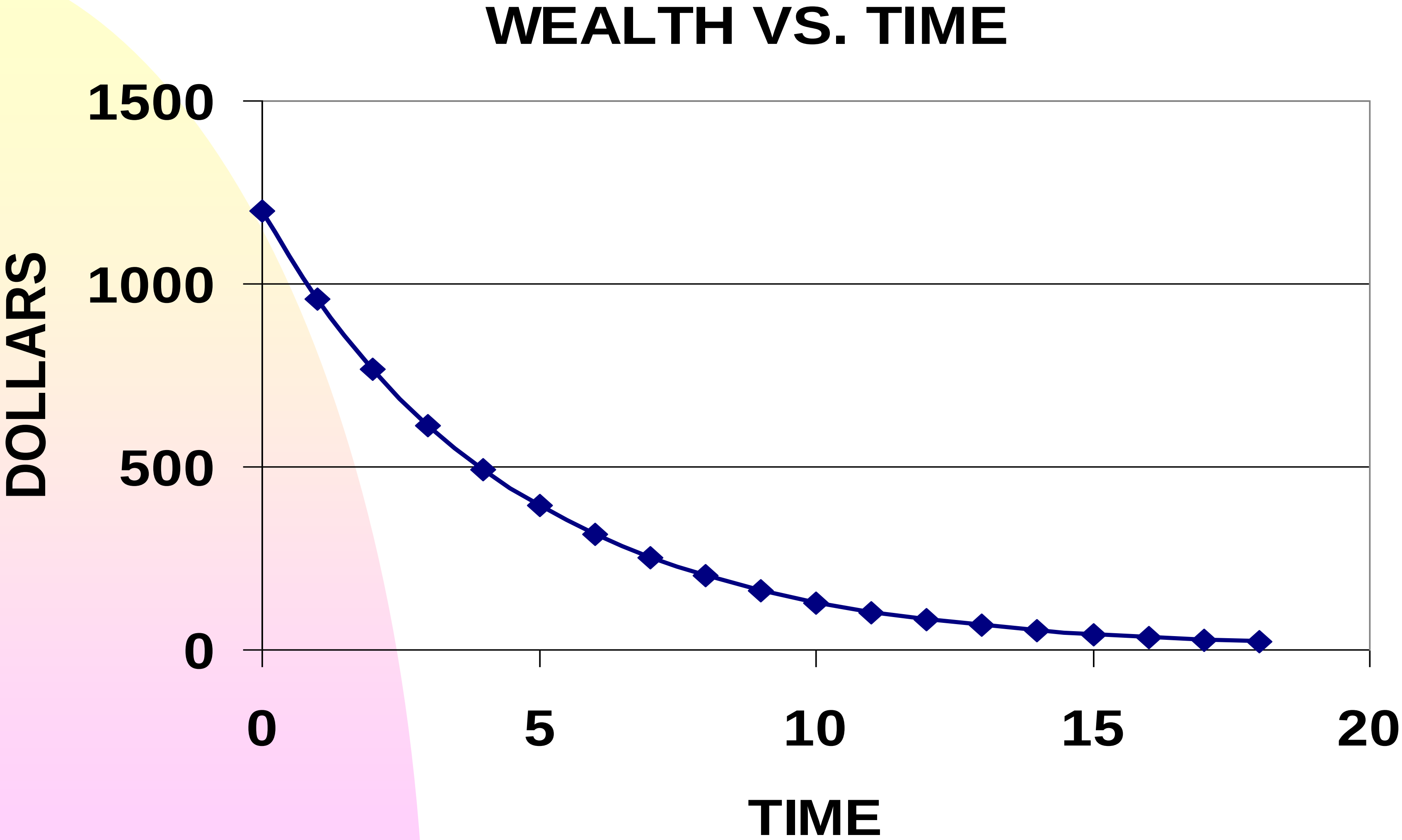
- Analogy ...



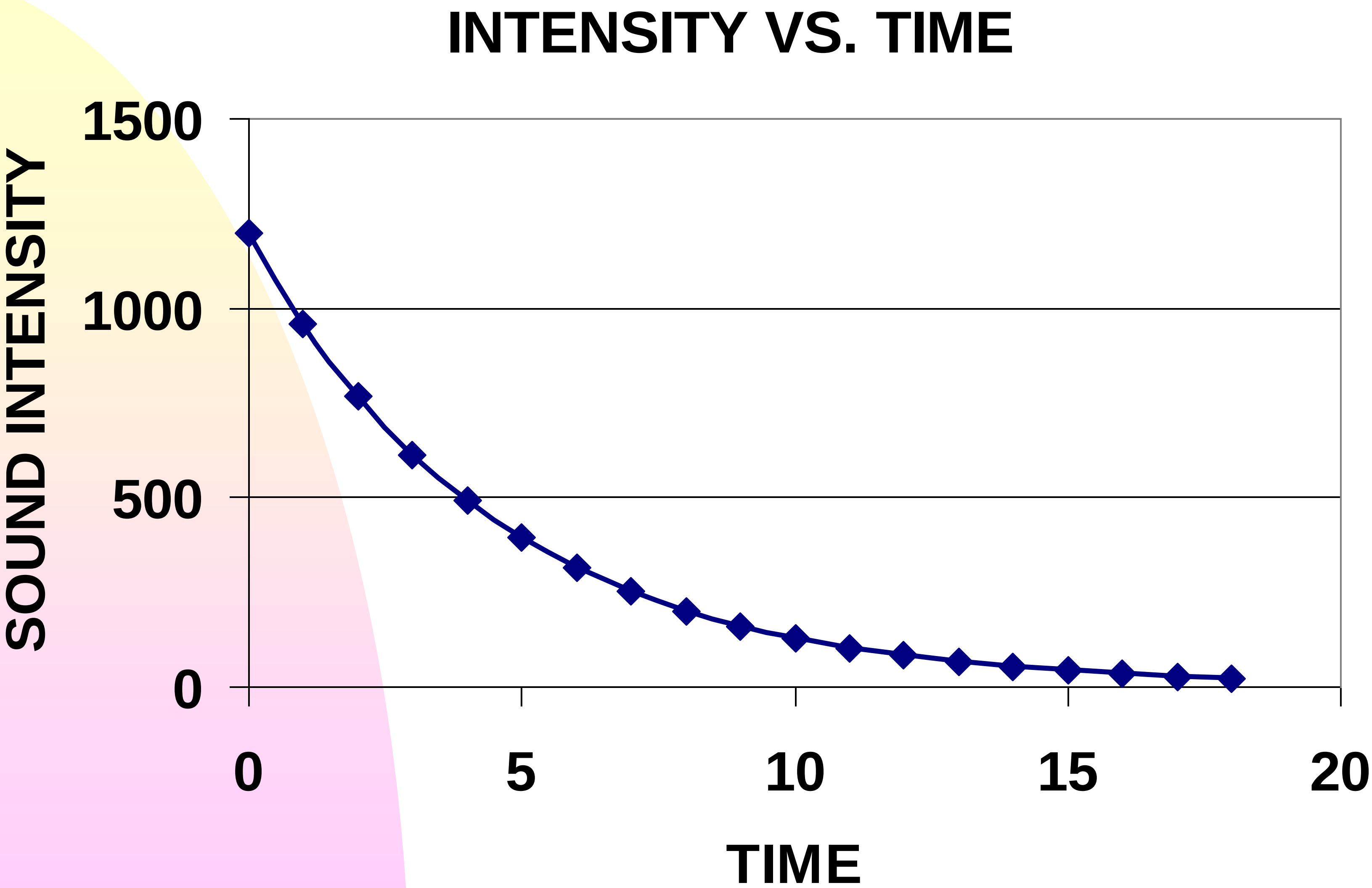
Reverberation Time

- WEALTH VS. TIME

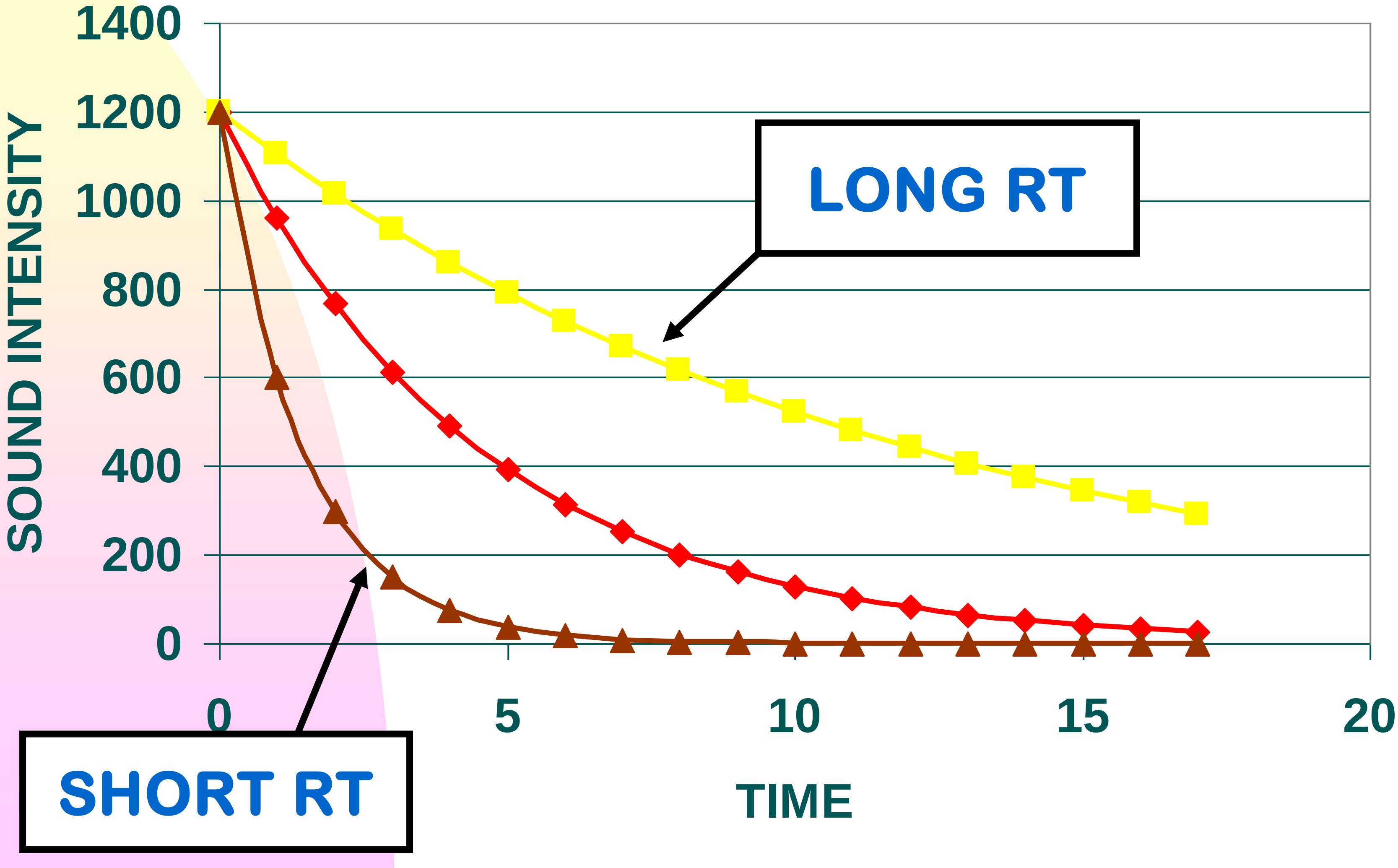
WEALTH	TIME
$ 1200.00	0
960.00	1
768.00	2
614.40	3
491.52	4
393.22	5
etc.	etc.



WEALTH VS. TIME
1500
1000
500
0
DOLLARS
0
5
10
15
20
TIME


INTENSITY VS. TIME
SOUND INTENSITY
1500
1000
500
0
0
5
10
15
20
TIME

INTENSITY VS. TIME



Reverberation time

- The Sabine equation gives the reverberation time *RT* of a room in seconds:

$$RT = \text{constant} \times \frac{\text{volume of room}}{\text{total surface absorption}}$$

$$= k\frac{V}{A}$$

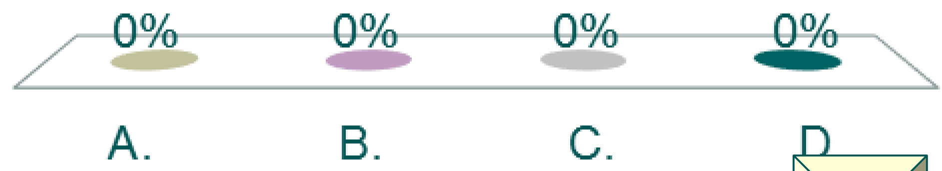
In order to decrease the reverberation time you should _____ the surface absorption coefficient α, or make the room _____.

A. increase … larger

B. increase … smaller

C. decrease … larger

D. decrease … smaller



Response Counter

90

In order to decrease the reverberation time you should ______ the surface absorption coefficient α, or make the room ______.

A. increase … larger

B. increase … smaller

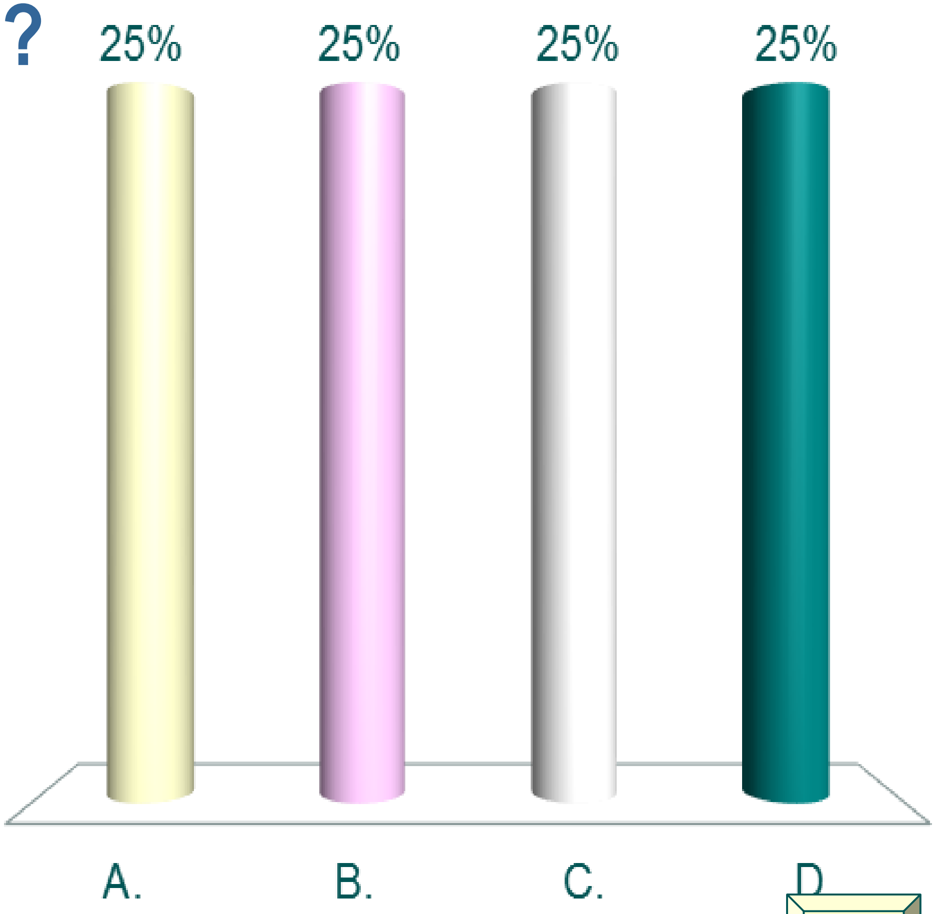
C. decrease … larger

D. decrease … smaller

More absorption means a faster decay of sound intensity, shorter RT. A smaller room means less time delay between reflections, shorter reverberation time.

A room has a reverberation time of 0.552 s when its total absorption *A* = 8.685. Changing the carpet decreases the total absorption to *A* = 5.610. What is the new reverberation time?

A. 0.230 s
B. 0.365 s
C. 0.855 s
D. 1.323 s



Response Counter

180

A room has a reverberation time of 0.552 s when its total absorption *A* = 8.685. Changing the carpet decreases the total absorption to *A* = 5.610. What is the new reverberation time?

A. 0.230 s

B. 0.365 s

C. **0.855 s**

D. 1.323 s

Use a ratio: $RT = kV/A$

$$\frac{RT_{\text{new}}}{RT_{\text{old}}} = \frac{\dfrac{kV}{A_{\text{new}}}}{\dfrac{kV}{A_{\text{old}}}} = \frac{A_{\text{old}}}{A_{\text{new}}} = \frac{8.685}{5.610} = 1.55$$

$$RT_{\text{new}} = 1.55 RT_{\text{old}} = 1.55(0.552\ \text{s}) = \boxed{0.855\ \text{s}}$$

(Optional at this time) You can learn how to calculate the *A* values on pp.112-114. This question is an adaptation of Practice Problem 2 on p. 114, which assumes $k = 0.161$ for 22°C air.