LECTURE 16 (1ST AFTER BREAK)
CHAPTER 6 - (5)

LOUDNESS, INTENSITY OF SOUND & SOUND PRESSURE

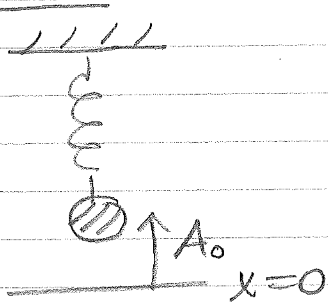
INTENSITY IS POWER CROSSING A UNIT AREA

POWER IS ENERGY PER UNIT TIME ⇒

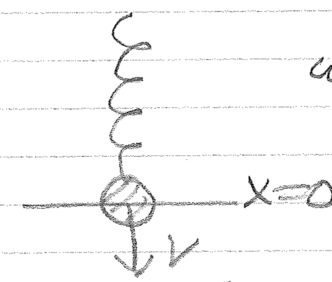
$I \equiv$ INTENSITY IS THE AMOUNT OF ENERGY CROSSING A UNIT AREA PER UNIT TIME

$$I = \frac{\text{WATTS}}{m^2} = \frac{\text{Joules}}{m^2 \cdot \text{sec}} = J/m^2 \cdot s$$

REVIEW



$$\frac{1}{2}kA_0^2 \rightarrow \frac{1}{2}mV^2 \quad V = \frac{k}{m}A_0$$

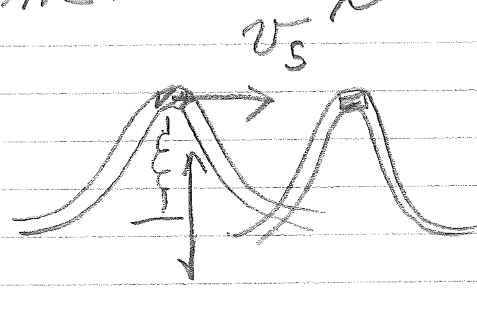


$$\omega_0 = \sqrt{k/m}$$
$$k = m\omega_0^2$$

$$KE = \frac{1}{2}m\omega_0^2 A_0^2 = \frac{1}{2}kA_0^2$$

THIS REPRESENTS THE ENERGY FROM THE UP / DOWN MOTION

WAVE $\quad v_s \sim$ SPEED OF THE WAVE



THE DISPLACEMENT ENERGY WRITTEN AS $\frac{1}{2}m\omega_0^2 A_0^2$ IS BEING TRANSPORTED

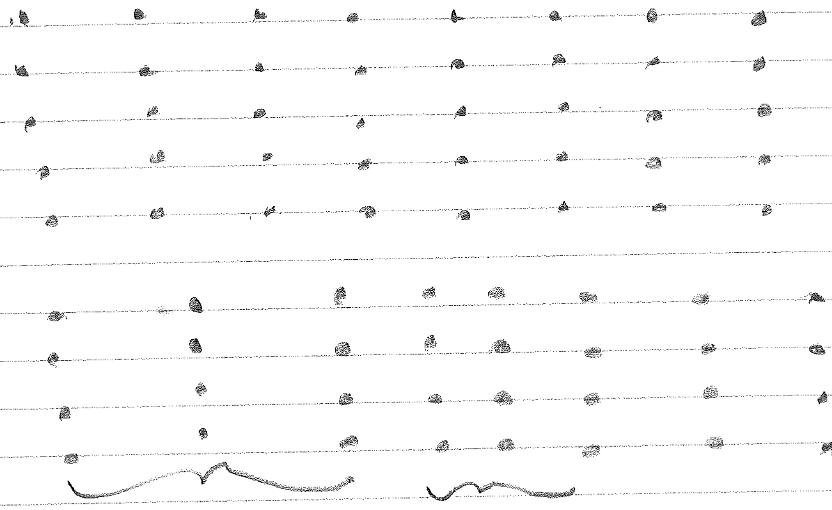
$\frac{1}{2}m\omega_0^2 A_0^2 v_s$ UNITS $\frac{E \cdot m}{s}$

$$\frac{1}{2}m\omega_0^2 A_0^2 v_s \rightarrow \frac{1}{2}\rho\,\omega_0^2 A_0^2 v_s = \frac{E}{m^3}\frac{m}{s} = \frac{E}{m^2 \cdot s} \checkmark$$

$$I = \rho v_s \omega^2 \frac{1}{2}A_0^2 \quad \text{MAX AMPLITUDE} \quad \langle A^2 \rangle = \frac{1}{2}A_0^2$$

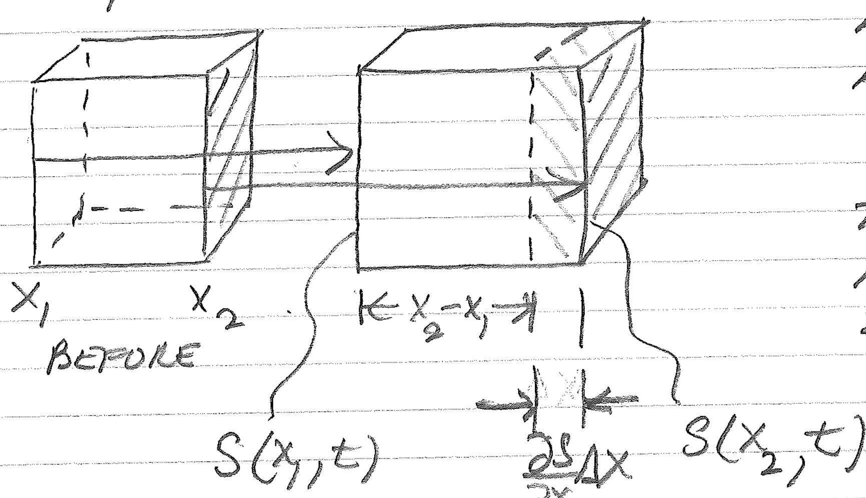
LOUDNESS / INTENSITY

IN A LONGITUDINAL PRESSURE WAVE THE DISPLACEMENT IS IN THE DIRECTION OF PROPAGATION.



BEFORE WAVE ARRIVES.

EXPANDED COMPRESSED



EACH POINT AT $X_1 \rightarrow$ A NEW POINT $S(X,t)$.

THE DISPLACEMENTS ARE NOT THE SAME — REGIONS ARE EXPANDED & COMPRESSED.

$$\Delta X = X_2 - X_1 \qquad X_2 = X_1 + \Delta X$$

$$S(X_2, t) = S(X_1 + \Delta X, t) = S(X_1, t) + \frac{\partial S}{\partial X}(X_2 - X_1)$$

$$= S(X_1, t) + \frac{\partial S}{\partial X}\Delta X$$

NOTE THAT THE VOLUME $A(X_2 - X_1)$ HAS CHANGED BY $\underbrace{A(S(X_2,t) - S(X_1,t))}_{\text{SHADED REGION}} = A\frac{\partial S}{\partial X}\Delta X = \Delta V$

CONNECTION WITH PRESSURE

BULK MODULUS $B = -V\frac{dP}{dV} = -V\frac{\Delta P}{\Delta V}$

$\Delta p = -B\frac{\Delta V}{V}$ EXPAND REGION $\Delta V = +$

$\Delta p = -$

$= -B\frac{A\frac{\partial S}{\partial x}\Delta x}{A\Delta x}$ THINK OF $pV = Nk_BT$ OR $pV^{\gamma} = $ CONSTANT

$\Delta p = -B\frac{\partial S}{\partial x}$

Δp IS MEASURED ABOVE & BELOW EQUILIBRIUM PRESSURE = ATMOSPHERIC PRESSURE FOR SOUND IN AIR.

DISPLACEMENTS OSCILLATE

TAKE $S(x,t) = S_m\cos(kx-\omega t)$

$\left.\frac{\partial S}{\partial x}\right)_t = S_m(+k)(-\sin(kx-\omega t))$

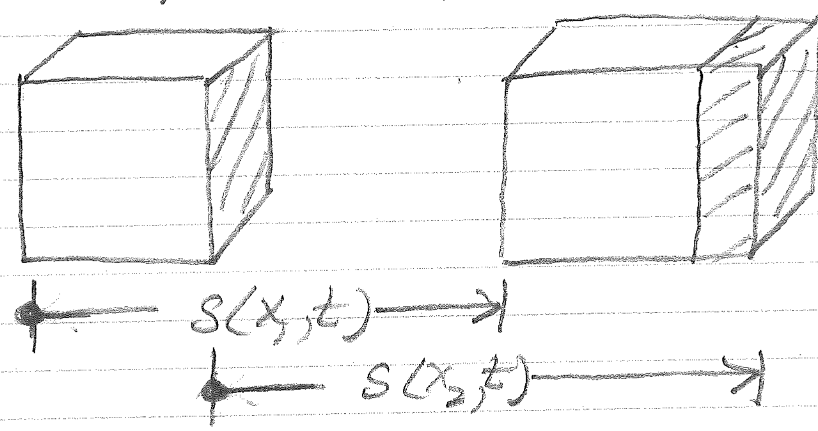
$\Delta p = +BS_m k\,\sin(kx-\omega t)$

USE $\underbrace{\sqrt{\frac{B}{\rho}} = v_s}_{\text{SPEED OF SOUND}}$ $B = \rho v_s^2$ $k = \frac{\omega}{v_s}$

$$\boxed{\begin{array}{l}\text{FOR } S(x,t) = S_m\cos(kx-\omega t) \\ \text{\& } \Delta p = \rho v_s\omega S_m\sin(kx-\omega t)\end{array}}$$

$S(x,t)$ & Δp ARE OUT OF PHASE

LOUDNESS / INTENSITY /



$$S = S_m \cos(kx - \omega t)$$

ΔE = ENERGY IN CUBE ΔM = MASS IN CUBE

ρ = DENSITY OF GAS. $\Delta m = \rho A \Delta x$

$$\Delta E = \frac{1}{2} \Delta m v_{MAX}^2 = \frac{1}{2} \Delta m (\omega^2 S_{MAX}^2)$$

$$= \frac{1}{2} \rho A \Delta x \, \omega^2 S_{MAX}^2$$

$$\text{POWER} = \frac{\Delta E}{\Delta t} = \frac{1}{2} \rho A \left(\frac{\Delta x}{\Delta t}\right) \omega^2 S_{MAX}^2$$

$\frac{\Delta x}{\Delta t} = v_s$ SPEED OF SOUND.

$$\boxed{I = \frac{\text{POWER}}{A} = \frac{1}{2} \rho v_s \omega^2 S_{MAX}^2} \qquad S_{MAX} \equiv S_m$$

$$\Delta P = \rho v_s \omega S_m \sin(kx - \omega t) \equiv \Delta P_m \sin(kx - \omega t)$$

$$\Delta P_m = \rho v_s \omega S_m \qquad \omega S_m = \Delta P_m / \rho v_s$$

$$\boxed{I = \frac{(\Delta P_m)^2}{2 \rho v_s}} \qquad \langle (\Delta P)^2 \rangle = \frac{1}{2} (\Delta P_m)^2$$

LOUDNESS- INTENSITY

THE EAR RESPONDS ~ LOGARITHMICALLY

A SOUND 10^6 TIMES IN INTENSITY IS NOT HEARD 10^6 TIMES AS LOUD.
OUR HEARING DOES NOT MEASURE ACOUSTICAL ENERGY LINEARLY.

DEVELOPE A SCALE FOR LOUDNESS THAT REFLECTS THIS NON-LINEAR, LOGARITHMIC RESPONSE.

ALEXANDER GRAHAM BELL UNIT IS

$1 \log_{10} I/I_0$ (SOMEWHAT LIKE THE RICHTER SCALE)

IN THIS UNIT INCREASIN I BY A FACTOR 10

$$1 \log_{10} 10I/I_0 = \underbrace{1 \log_{10} 10}_{\text{INCREASE: 1 BELL}} + \underbrace{1 \log I/I_0}_{\text{ORIGINAL SOUND}}$$

INCREASE IS ONLY 1 UNIT
TO MAKE THE INCREASE LARGER USE

$$\underbrace{10}\log_{10} I/I_0 = L_I \text{ IN DECIBELS dB}$$

THEN $10 \log_{10} 10I/I_0 = \underbrace{10\,dB}_{\text{INCREASE}} + \underbrace{10 \log_{10} I/I_0}_{\text{ORIGINAL SOUND}}$

THE $I_0 = 10^{-12}$ WATTS/m^2.

AN INTENSITY OF 1 WATT/m^2 HAS LOUDNESS IN dB

$$10 \log 1/10^{-12} = 10(\log 1 - \log_{10} 10^{-12})$$
$$= 10(0 + 12) = 120\,dB$$ THIS IS VERY VERY LOUD.

$$\log_{10} X/y = \log_{10} X - \log_{10} y$$
$$\log X^a = a \log X$$