Lecture 1

PHYS 2112

Course web site is markwilde.com/teaching

Introduction

Review Syllabus

This week we cover fluids briefly & thermodynamics

understanding fluids is important for a number of engineers.

- Nuclear engineer: fluid flow in hydraulics for nuclear reactor
- Biomedical engineer: blood flow
- Aeronautical engineer: hydraulics for wing flaps that allow airplane to land

- fluid is a substance that can flow
  - includes liquids & gases but not solids

Solids have constituent atoms organized in a regular 3D lattice & so does not allow for flow
- But this is not the case for liquids & gases

Density & Pressure

more useful to consider these quantities rather than mass & force (but related)

To find density @ given point of a fluid, isolate a small volume element ΔV & measure mass Δm around that point

Density $\rho = \frac{\Delta m}{\Delta V}$ at that point

(should actually be limit as volume element becomes small)

Assuming fluid sample is large relative to atomic dimensions (uniform density assumption), then

$$\rho = \frac{m}{V}$$ (uniform density)

Density is a scalar

Units are $\frac{\text{kilograms}}{\text{cubic meter}} = \frac{kg}{m^3}$

density of a gas varies considerably w/ pressure

Pressure

$$p = \frac{\Delta F}{\Delta A}$$

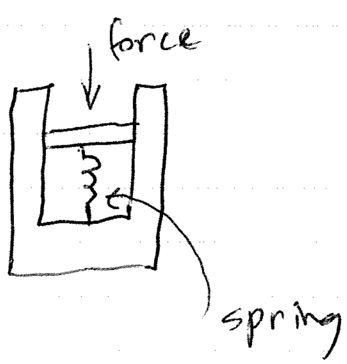
pressure at a given point in a fluid is force per unit area

If force is uniform over a flat area (evenly distributed over area)

then $p = \frac{F}{A}$ (pressure of uniform force over a flat area)

How to measure pressure?

Place a sensor in liquid or gas



- force pushes spring down & can be measured & read out
- Area is known

can then calculate pressure

Given a fluid @ rest, pressure is the same no matter how the sensor is oriented.

Pressure is a <u>scalar</u>

(involves only magnitude of force)

Units of pressure - $\frac{\text{Newton}}{m^2}$

reminder:

$\text{Newton} = \frac{kg \cdot m}{s^2}$

units of pressure are also called

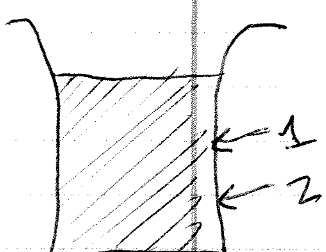
pascals = $\frac{\text{Newton}}{m^2}$ abbreviated as Pa

Another common unit is atm $= 1.01 \times 10^5$ Pa atm = atmospheres - approximate average pressure of atmosphere at sea level.

Example: Pressure increases w/ depth in a liquid (scuba divers know about this)

What is change in pressure w.r.t. height?

can calculate using density



Pick out two heights

fluid is static (assumption)

& so sum of forces is equal to zero

forces include downward force due to gravity, downward pressure force @ 1 upward force @ 2

$$\vec{F}_1 + \vec{F}_2 + \vec{F}_g = 0$$

$$p\vec{A} + (p+\Delta p)\vec{A} + m_i\vec{g} = 0$$

↑ area vector ↑ mass @ point

$$\Rightarrow \quad pA - (p+\Delta p)A - m_i g = 0$$

$$\rho = \frac{m}{V} \Rightarrow m = \rho V = \rho A \Delta y$$

$$\Rightarrow \quad -\Delta p A - \rho(A\Delta y)g = 0$$

$$\Rightarrow \quad \frac{\Delta p}{\Delta y} = -\rho g$$

For incompressible fluid, ρ is constant so that

$$p_2 - p_1 = -\rho g (y_2 - y_1)$$

18-1 Temperature

thermodynamics - study & applications of thermal energy of systems.

central concept is temperature

Measured in Kelvins - K

temperature has no upper limit but there is a lower limit, which is zero K.

Room temperature is 290K

At beginning of universe, temperature was 10^{39} K. After expansion, it cooled to an average of 3K.

Zeroth law of thermodynamics

properties of various bodies change w/ temperature

E.g., as temp. increases, volume of a liquid increases,

electrical resistance of a wire increases,

pressure exerted by a gas increases

these can be used to measure temperature

Notion of thermal equilibrium:

Put a thermoscope T into contact w/ body A. After some time, numbers displayed by thermoscope settle to fixed value. Also, suppose every measurable property no longer changes.

then A & T are in
thermal equilibrium

Now suppose T is placed into
contact w/ another body B &
they relax to thermal equilibrium.

If the numbers read on thermoscope T
are same as found previously,
then it is found experimentally that
A & B are in thermal equilibrium

Zeroth law of thermo:

If A & B are each in thermal
equilibrium w/ T, then they are in
thermal equilibrium w/ each other.

- Another way of interpreting this is that every body has a well defined <u>temperature</u>.
- When two bodies are in thermal equilibrium, their temperatures are equal.

Zeroth law establishes <u>temperature</u> as a legitimate and well defined physical concept.

<u>How to define Kelvin scale?</u>

The lowest temperature is set to zero.

- to have a scale, we need another point, and it is good to have some reproducible thermal phenomenon.
- take it to be the <u>triple point of water</u>

- The triple point of water is a unique temperature at which liquid water, solid ice, & water vapor can coexist in thermal equilibrium.
- This temperature is set to be

$$T_3 = 273.16 \text{ K}$$

↑ for triple point of water

⇒ 1 K is equal to $\frac{1}{273.16}$ of difference between triple-point temperature of water & absolute zero.

Celsius = translated version of Kelvin scale

$$T_c = T - 273.15$$

0°C is freezing point of water
100°C is boiling point of water

Fahrenheit:

$$T_F = 9/5\, T_c + 32$$

Thermal Expansion

Materials expand w/ increase in temperature.

A bridge requires expansion slots so that sections of the bridge have room to expand on hot days (otherwise bridge would buckle)

Linear Expansion

Suppose that a metal rod of length L has temperature raised by ΔT, length increases by

$$\Delta L = L \alpha \Delta T$$

where α is <u>coefficient of linear expansion</u>

α depends on material & has units "per Kelvin"

Volume Expansion

If all dimensions of a solid expand w/ temperature, then increase in volume is

$$\Delta V = V \beta \Delta T$$

- V ← original volume
- β ← coefficient of volume expansion
- ΔT ← change in temp.

$$\beta = 3\alpha$$

Examples:

Expansion of Brooklyn Bridge

Steel bed of bridge is 490 m @ 20°C. If temperature extremes are −20°C + 40°C,

how much will it contract + expand?

$\alpha_{steel} = 12 \times 10^{-6}\ °C^{-1}$

$\Rightarrow \Delta L = \alpha_{steel} L_0 \Delta T$

$= 12 \times 10^{-6} (°C^{-1}) \cdot 490 m \cdot 60°C$

$= 35 cm$

$40-(-20)=60$

Thermal Expansion and a Pendulum Clock

Pendulum clock made of brass keeps time accurate @ 20°C.
If clock operates @ 0°C, does it run fast or slow per day?

$$T_{\text{simple pendulum}} = 2\pi \sqrt{\frac{L}{g}}$$

$$L = L_0 + \Delta L$$
$$= L_0 + \alpha_{brass} L_0 \Delta T$$

If original period was 1 second,

$$\Rightarrow L_0 = \left(\frac{1s}{2\pi}\right)^2 g = 24.824 \text{ cm}$$

$$\alpha_{brass} = 19 \times 10^{-6} \, (°C)^{-1}$$

$\Rightarrow L = (24.824 \text{ cm})(1 + 19 \times 10^{-6} (°C)^{-1} (-20°C))$

$= 24.82 \text{ cm} \cdot 0.9996$

$=$ ~~24.814~~

24.814 cm

$\Rightarrow$ new period is

$$T = 2\pi \sqrt{\frac{24.814}{9.8}} = 0.9998 \text{ s}$$

ticks in a day

$= 24 \cdot 60 \cdot 60 = 86400$

for new clock # ticks is

$$\frac{86400}{.9998} = 86416$$

16 extra ticks per day!