1. Invent Yourself: Physics
Precise Weighting

Tibor Basletić Požar

1. Invent yourself: Physics

Topic: precise weighting. Study the physical effects that influence precise weighting of solid objects with a mass of 10 to 100 g.

Types of scales

Balance scale

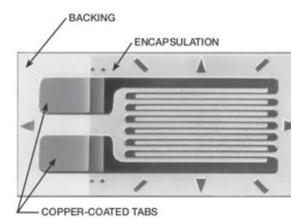
- with leverage

-> balance of force on both plates (+ *Law of the Lever*)
-> mass = reference mass

Spring scales

-> Hooke's law (spring)
-> Δx ~ force ~ mass

Electronic scales



-> strain gauge
-> mass ~ force ~ pressure ~ strain ~ resistance
-> not necessarily proportional

we are measuring force, not mass

Source of errors - physical effects

- depends on scale type (balance/spring/electronic scale)

Balance scale:
- friction on different scale parts
- external influence (air gust, shaking ...)
- reference mass precision

Spring scale:
- nonlinearity of spring
- fatigue of spring material
- strenght of gravitational force (altitude)

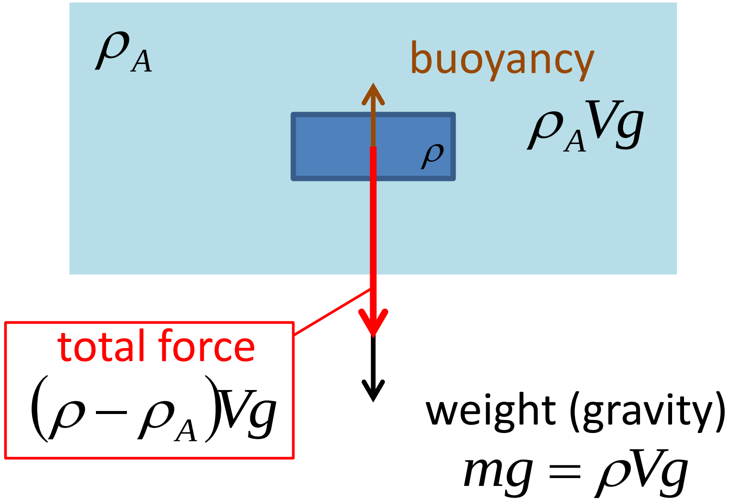
Electronic scale:
- electro/magnetic fields
- strenght of gravitational force (altitude)

Common to all scales:
- temperature change/nonuniformity (thermal expansion of scale parts)
- buoyancy
- friction
- dust, water condensation
- magnetic field

... and so on ...

(Here we do not discuss: gross errors (mistakes), systematic errors, random errors).

Buoyancy



- m - body mass
- ρ - body density
- V - body volume
- ρ_A - air density
- g - accel of gravity

Two weights on balanced scale

m_1, ρ_1, V_1 $\quad$ m_2, ρ_2, V_2

In air -> total forces are equal:

$$m_1 g - \rho_A V_1 g = m_2 g - \rho_A V_2 g$$

If we remove air -> no more balance

$$m_1 g \neq m_2 g$$

$$\rho_1 > \rho_2 \Rightarrow m_2 > m_1$$

Buoyancy

- relative mass difference:

$$\frac{\Delta m}{m_1}=\frac{m_2-m_1}{m_1}=\frac{1/\rho_2-1/\rho_1}{1/\rho_A-1/\rho_2}$$

$$\frac{\Delta m}{m_1}\approx\frac{\rho_A}{\rho_2-\rho_A}$$ for $\rho_1 >> \rho_2$ (e.g. lead counterbalance)

Experiment:

- glass ball:
  m_2 = 67 g (by digital scale; ‘wrong’ mass)
  V_2 = 3590 cm^3
  ρ_2 = 18.6 kg/m^3

- lead/steel counterbalance:
  m_1 = 63 g
  $V_1 << V_2$
  $\rho_1 > 10^3$ kg/m^3 $>> \rho_2$

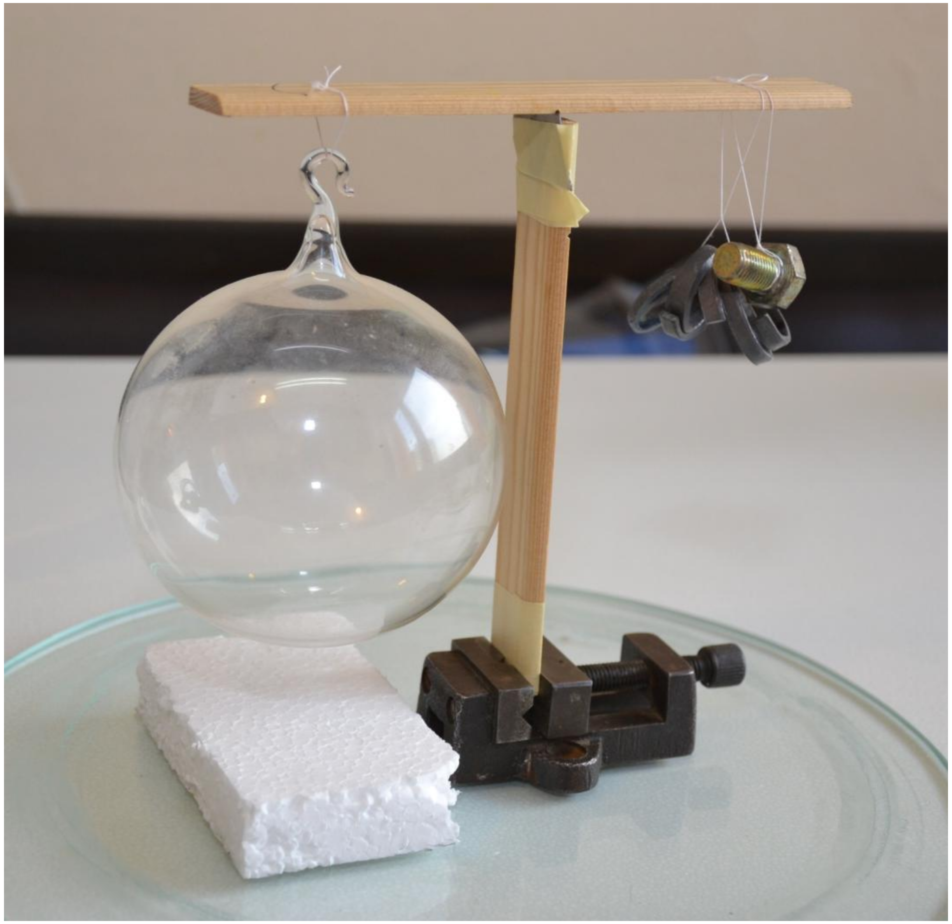
air density: ρ_A = 1.22 kg/m^3

$$\frac{\Delta m}{m_1}\approx 7.0\%$$

not so small

Buoyancy

Home made balance scale



In air -> equilibrium

In vacuum -> ball is heavier

Conclusion

- we studied various mass scale types
- measuring mass -> actually we measure force
- plenty of physical effects which can infulence measurements
- certain errors -> dependent on scala type
- other errors -> common to all scale types
- for example: buoyancy
- we show effects of buoyancy: balance in air - vs - balance in vacuum
- buoyancy -> not so small (for light materials)

Literature:

https://en.wikipedia.org/wiki/Weighing_scale

https://en.wikipedia.org/wiki/Strain_gauge

Constantan Alloy: Strain Gauge Selection, http://www.vishaypg.com/docs/11055/tn505.pdf

THANK YOU
FOR YOUR ATTENTION

Type of errors

Gross errors (mistakes)

- experimentator errors
- e.g. wrong readings of instrument
- e.g. influence of external effects
- usually very large
- data deviate from others
- must be eliminated and/or discarded

Systematic errors

- errors of experimental devices
- e.g. voltmeter (consistently) shows 5% larger voltage
- e.g. ruler with shifted zero
- not so critical
- measured data may be renormalized afterwards

Random errors

- due to high static friction in mechanism
- e.g. current noise due to granularity of electron quantization
- cannot be eliminated

In mass weighting, all error types are possible, either due to the design of the mass scale or external influence.

(Should we give number of examples for errors, for all mass scale types?)

Precision vs. accuracy

Precision - how many digits can be reliably (and reproducibly) measured.
- e.g. mass scale gives m = 56.3427 g
- very precise result - 6 digits
- may be wrong, for example, true mass may be 58.232 g

Accuracy - how accurate the measurement is.
- e.g. mass scale can give m = 58.2 g
- less precise than above - only 3 digits
- however, the accuracy is much better