Why is Scaling important?

"You can drop a mouse down a thousand-yard mine shaft; and, on arrival at the bottom it gets a slight shock and walks away, provided that the ground is fairly soft. A rat is killed, a man is broken and a horse splashes." J. B. S. Haldene.

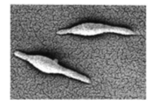
Why is Scaling important?

- Scaling affects everything from metabolic heat production and exchange to circulation.
- Think of nutrient dispersal throughout a small prokaryote versus a blue whale.

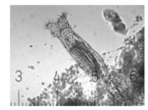
SURFACE AREA and VOLUME

Huge Range of Sizes!

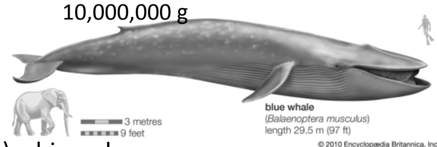
- Single celled organisms (*Mycoplasma*)
  - 0.1 pg (1 x 10^{-13} g) 0.0000000000001 g



- Rotifers
  - 0.01 µg (1 x 10^{-8} g) 0.00000001 g



- Blue whale (*Balaenoptera musculus*)
  - 10,000 kg (1 x 10^{8} g) 10,000,000 g

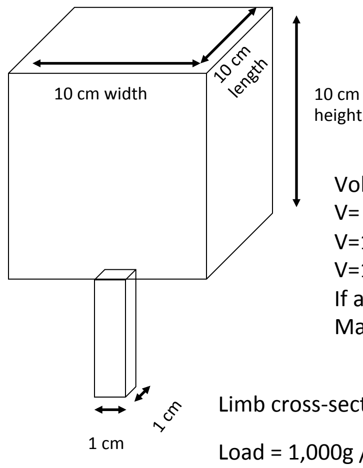


- Giant Redwood Trees (*Sequoia* spp.) = bigger!
- Living organisms range 1 x 10^{21+} in size
- Animals range 1 x 10^{16} in size

How does getting bigger influence physiology

- Gravity
  - Circulation
  - Movement and Locomotion
- Surface Area/Volume Ratio
  - Respiration
  - Digestion
  - Water Balance
  - Thermoregulation

Getting bigger for terrestrial organisms



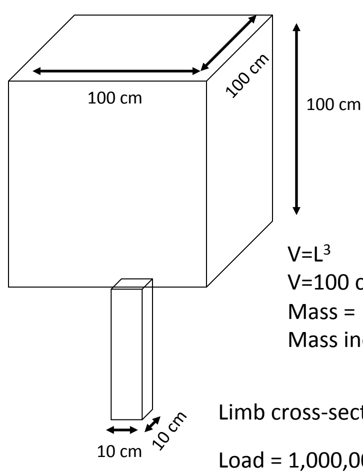
Assume this animal is a cube!

Volume (V) = L X L X L
$V = L^3$
V=10 cm X 10 cm X 10 cm
$V = 10^3 = 1{,}000\ cm^3$
If animal density is $1000 kg/m^3$ … $1 kg/dm^3$ … $1 g/cm^3$
Mass = 1,000 g (1 kg)

Limb cross-sectional area = L x L….L^2… 1 cm X 1 cm = $1\ cm^2$

Load = 1,000g / $1\ cm^2$

10 times bigger!

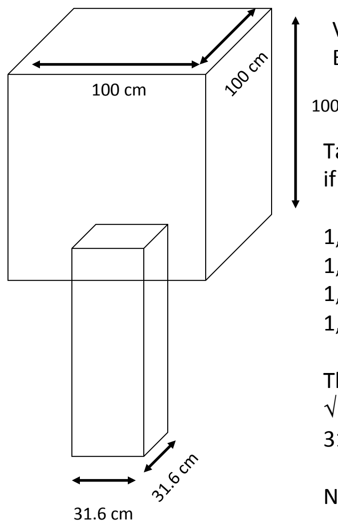


$V = L^3$
V=100 cm X 100 cm X 100 cm = $1{,}000{,}000\ cm^3$
Mass = 1,000,000 g (1,000kg)
Mass increased 1000x with a 10x increase in length

Limb cross-sectional area = L^2…10 cm X 10 cm = $100\ cm^2$

Load = 1,000,000g / $100\ cm^2$
= 1,000kg / $100\ cm^2$
= 10 kg / cm^2
= 10,000 g/cm^2 10x more load even if the limb is 10x bigger

How much bigger does the limb need to get to take the same load as when it was 10x smaller?



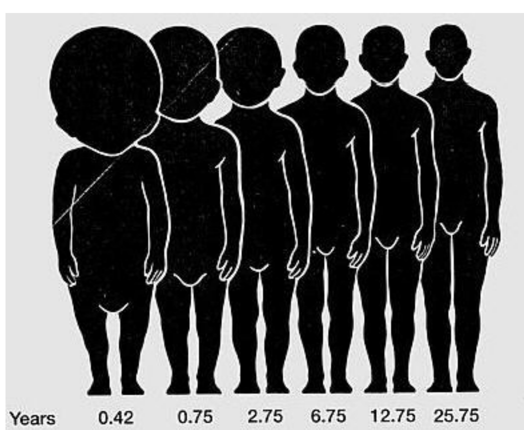
$V = L^3$ = 100 cm X 100 cm X 100 cm = 1,000,000 cm^3
Estimated mass = 1,000,000 g (1,000 kg)

Target load = 1,000 g / cm^2 (1kg / cm^2)
if the animal weighs 1,000,000g then it needs

1,000,000g / Xcm^2 = 1000 g/cm^2
1,000,000g = 1,000cm^2 * X
1,000,000g/1,000cm^2 = X
1,000g/cm^2 = X

Thus: Limb cross-sectional area = L x L = L^2 .. L=$\sqrt{L^2}$
$\sqrt{1000 cm^2}$ = 31.622 cm
31.622 cm X 31.622 cm = 1,000 cm^2

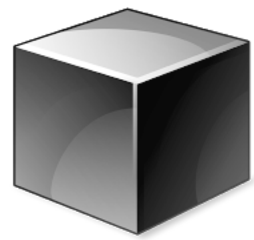
Need increase length from 10 cm to 31.6 cm (3x)



Cells are sphere-like

- Surface area of cube: L^2
- Volume of cube: L^3

Area = L^2 L= $(Area)^{1/2}$
Volume = L^3 Length = $(Volume)^{1/3}$
Area = $Volume^{1/3} * Volume^{1/3}$ $(x^a)(x^b) = x^{a+b}$
Area = **$(Volume)^{2/3}$**

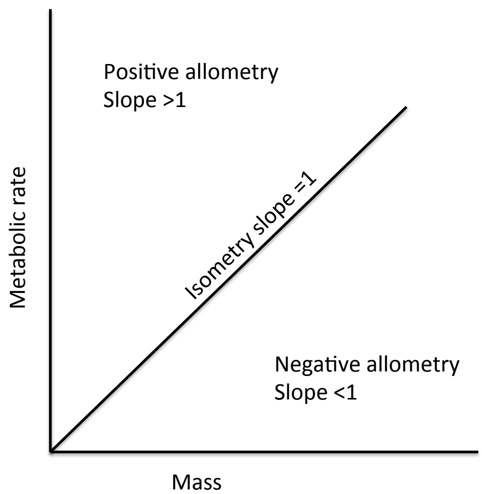


- Surface area of sphere: $4\pi r^2$
- Volume of sphere: $4/3 \pi r^3$
- $SA/V = 4\pi r^2 / 4/3\pi r^3 = 3/r$

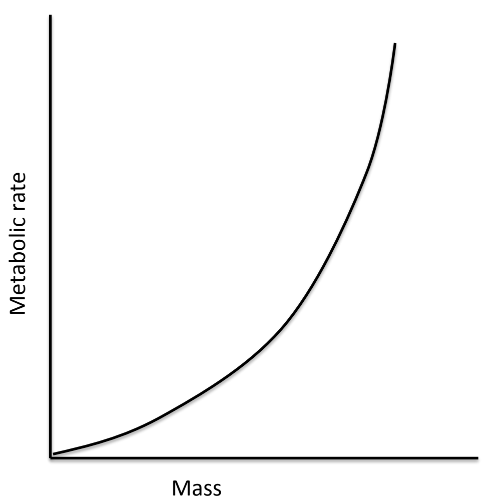
Things to remember from math 101

$$(x^a)(x^b) = x^{a+b}$$
$$1/x^a = x^{-a}$$
$$x^a/x^b = x^{a-b}$$
$$(x^a)^b = x^{ab}$$
$$x^0 = 1$$

Linear form: $y=mx+b$ MR=(Mass*slope) + intercept



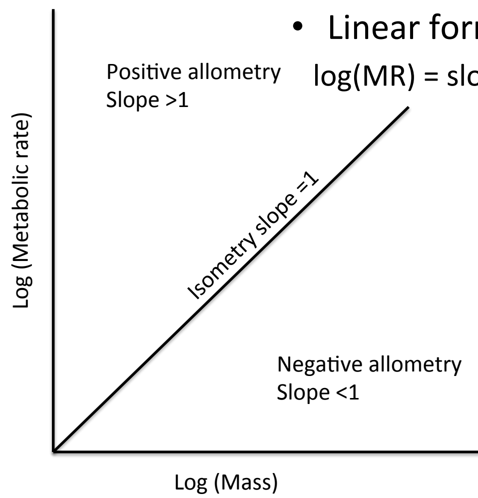
Exponential form: $y=bM^x$ $MR=intercept*(Mass)^{slope}$

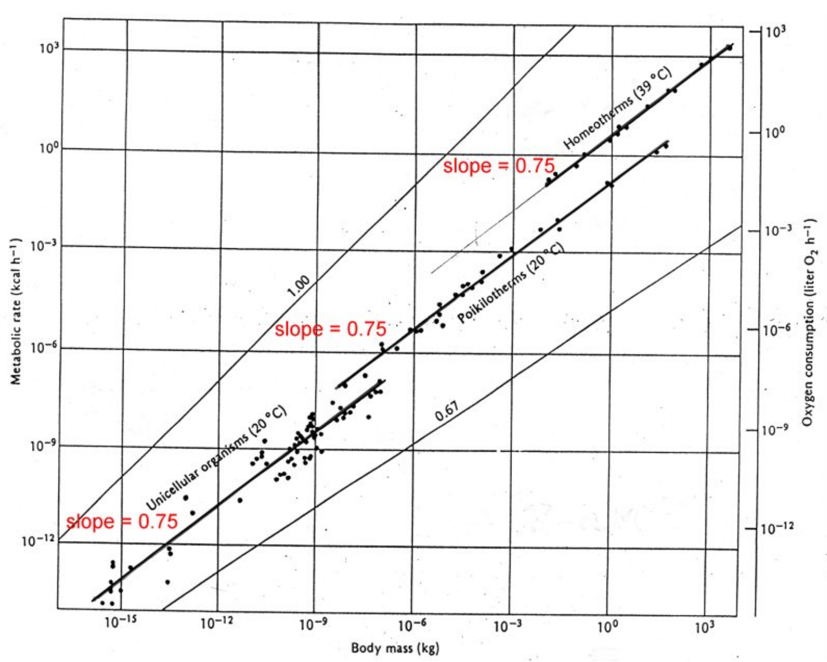


Exponential form: $y=bM^x$ $MR=intercept*(Mass)^{slope}$

- Linear form:

log(MR) = slope* log(Mass)+log(intercept)





Metabolic rate

The rate of energy consumption : Total energy use over time

1. indicates how much food animal needs
2. is a measure of total physiological activity
3. measures demand animals can place on an ecosystem

Ways to measure MR

A. Direct Calorimetry-measure heat output of an animal
    calorie = energy needed to elevate 1g water by 1°C

B. Indirect Calorimetry- by way of oxygen consumption or CO_2 production
    1 liter of oxygen consumed = 4.83kcal production (depending on diet)

Respiratory exchange ratio, *R:*
R= Moles of CO_2 produced per time / Moles of O_2 consumed per time

Value of 1= pure carbohydrate diet, = 0.7 lipid based diet

Metabolic rate

Standard Metabolic Rate (SMR) no activity, no digestion assimilation, no stress

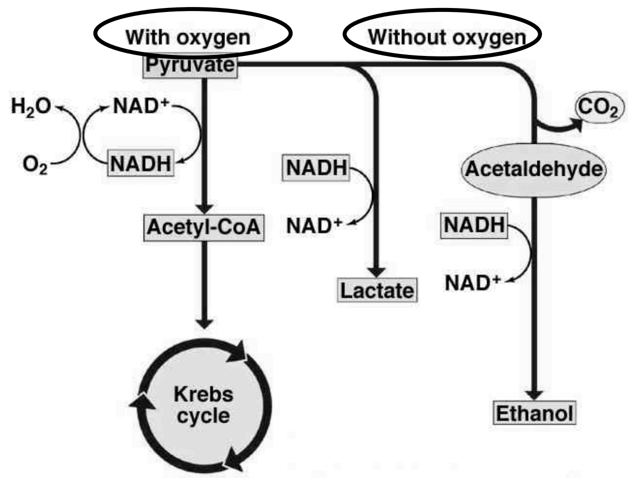
Basal Metabolic Rate (BMR) usually applied to endotherms

Routine Metabolic Rate (RMR) averaged for all time

Maximum Metabolic rate (MMR) peak value or mean peak value

What affects MR:
- *Age*
- *Gender*
- *Body temperature*
- *Environmental temperature*
- *Type amount of food*
- *Activity level*
- *Homeostasis*
- *Time of day*
- *Body size*

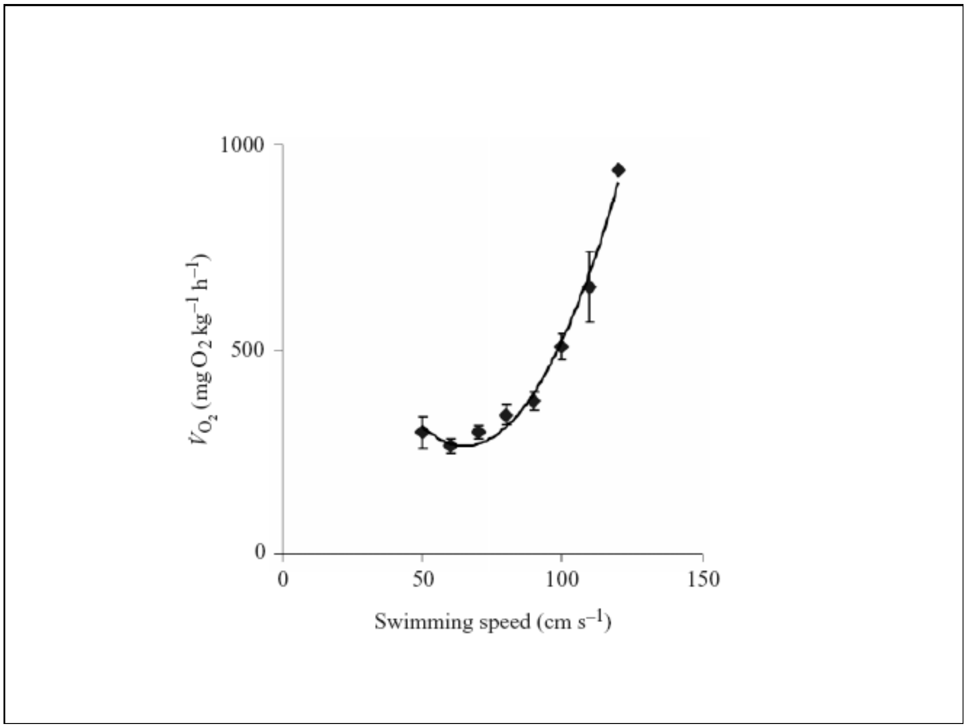
The fate of pyruvate



How do we measure metabolic rate?

In the field: telemetry
activity
radioactive labels

In the lab: Open systems
Closed systems


1000
500
0
V_{O_2} (mg O_2 kg^{-1} h^{-1})
0
50
100
150
Swimming speed (cm s^{-1})