Physics 1021

Spring 2012
Estimates: length and time scales for cells

Estimates
The facts

First things first
You need to know some numbers

You need to know how big things are

- Macromolecules (DNA, proteins, lipids) are about 1 nm in diameter
- Bacteria and ecoli are about 1 μm in size
- Eukaryotic cells (those with a nucleus) are about 100 μm in size
- Water has density 1g/cm^3 = 1 g/ml
- 1 Dalton = 1Da = mass of 1 hydrogen atom = 1 amu = 1.67 x 10^{-27} kg
- 1 mole = 6 x 10^{23} things
- See next slide for more

You need to know the prefixes … memorize these!

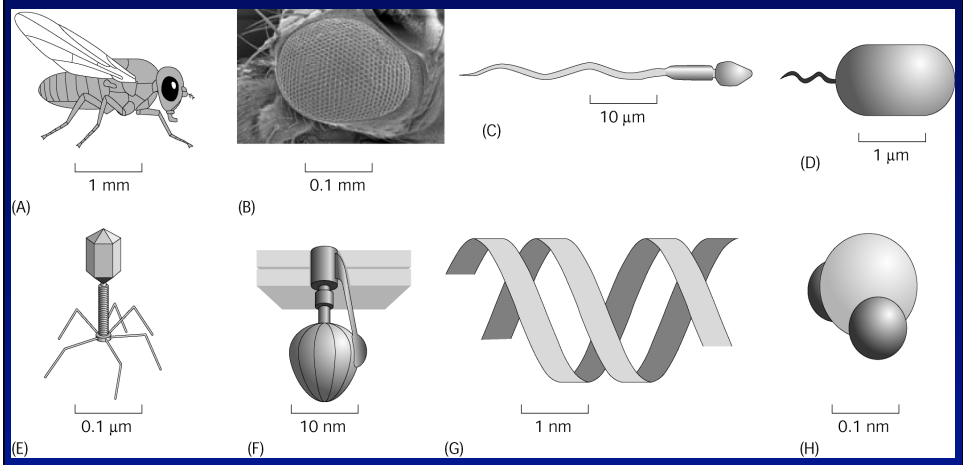
- femto = f_ = 10^{-15}
- pico = p_ = 10^{-12}
- Nano = n_ = 10^{-9}
- micro = μ_ = 10^{-6}
- milli = m_ = 10^{-3}
- nothing = _ = 10^{0}
- kilo = k_ = 10^{3}

- …. m_ = mg, mm, ml, etc.

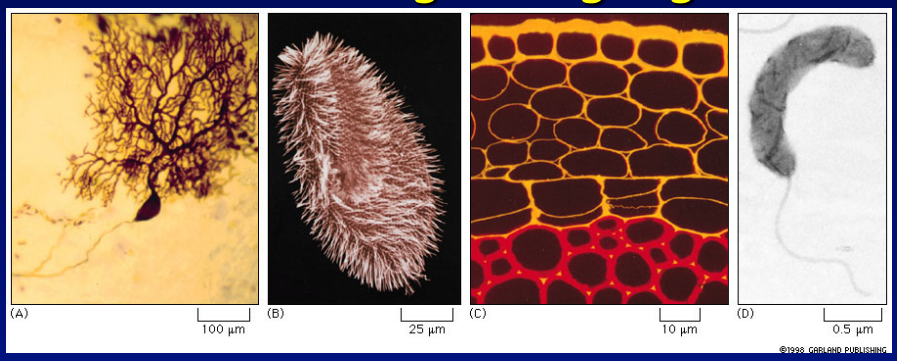
Some sizes

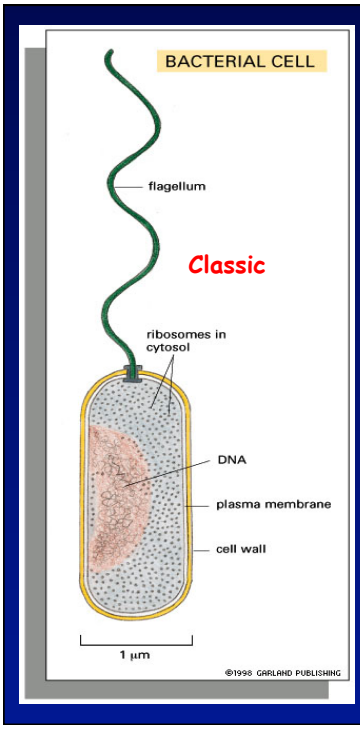
	Quantity of interest	Symbol	Rule of thumb
E. coli	Cell volume	$V_{E.coli}$	$\approx 1\,\mu m^3$
	Cell mass	$m_{E.coli}$	≈1 pg
	Cell cycle	$t_{E.coli}$	≈3000 s
	Cell area	$A_{E.coli}$	$\approx 6\,\mu m^2$
	Genome length	$N_{bp}^{E.coli}$	$\approx 5 \times 10^6$ bp
	Swimming speed	$v_{E.coli}$	≈20 μ m/s
Yeast	Volume of cell	V_{yeast}	$\approx 60\,\mu m^3$
	Mass of cell	m_{yeast}	≈60 pg
	Diameter of cell	d_{yeast}	≈5 μm
	Cell cycle time	t_{yeast}	≈200 min
	Genome length	N_{bp}^{yeast}	$\approx 10^7$ bp
Organelles	Diameter of nucleus	$d_{nucleus}$	≈5 μm
	Length of mitochondrion	l_{mito}	≈2 μm
	Diameter of transport vesicles	$d_{vesicle}$	≈50 nm
Water	Volume of molecule	V_{H_2O}	$\approx 10^{-2}$ nm^3
	Density of water	ρ	1 g/cm^3
	Viscosity of water	η	≈1 centipoise (10^{-2} g/(cm s))
	Hydrophobic embedding energy	$\approx E_{hydr}$	25 cal/(mol Å^2)
DNA	Length per base pair	l_{bp}	≈1/3 nm
	Volume per base pair	V_{bp}	≈1 nm^3
	Charge density	λ_{DNA}	2 e/0.34 nm
	Persistence length	ξ_P	50 nm
Amino acids and proteins	Radius of "average" protein	$r_{protein}$	≈2 nm
	Volume of "average" protein	$V_{protein}$	≈25 nm^3
	Mass of "average" amino acid	M_{aa}	≈100 Da
	Mass of "average" protein	$M_{protein}$	≈30,000 Da
	Protein concentration in cytoplasm	$c_{protein}$	≈300 mg/ml
	Characteristic force of protein motor	F_{motor}	≈5 pN
	Characteristic speed of protein motor	v_{motor}	≈200 nm/s
	Diffusion constant of "average" protein	$D_{protein}$	$\approx 100\,\mu m^2/s$
Lipid bilayers	Thickness of lipid bilayer	d	≈5 nm
	Area per molecule	A_{lipid}	$\approx \frac{1}{2}$ nm^2
	Mass of lipid molecule	m_{lipid}	≈800 Da

Some shapes and sizes
Flies to water



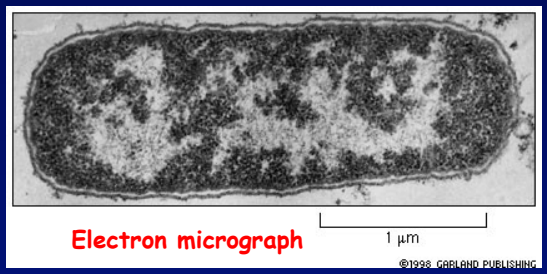
Cells – Molecular cities
Lots of things are going on





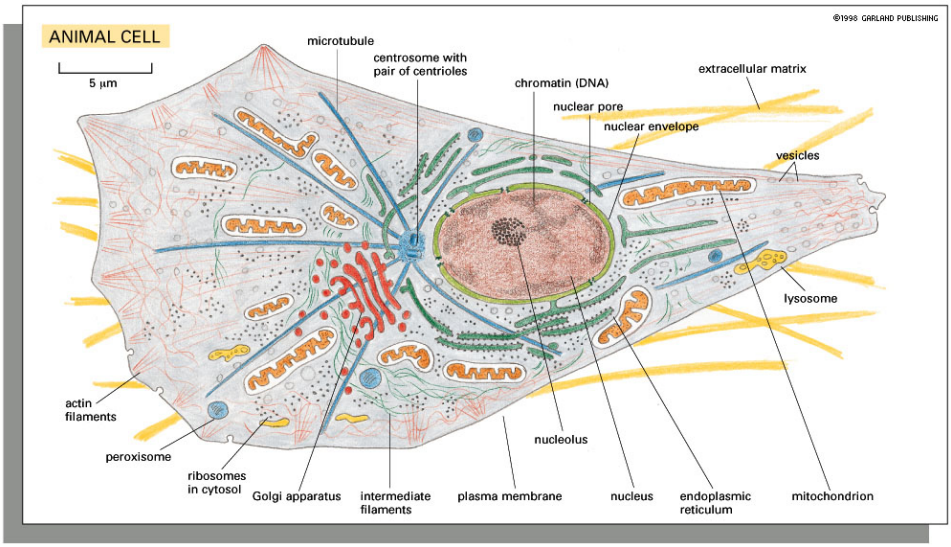
eColi, 3 views

– notice the scale bar in each one

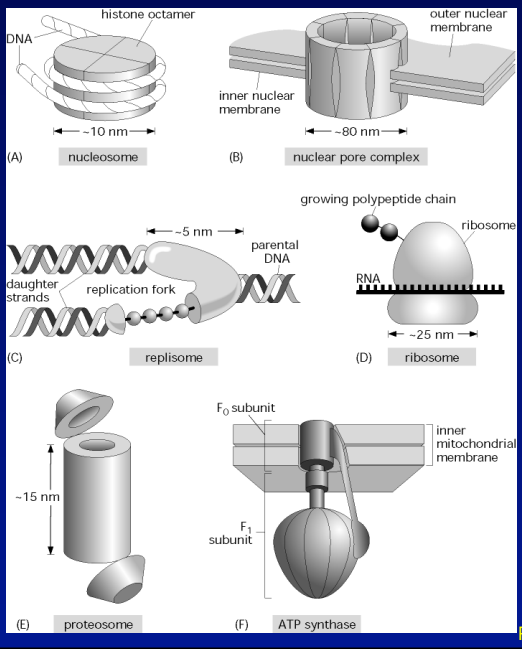


Electron micrograph

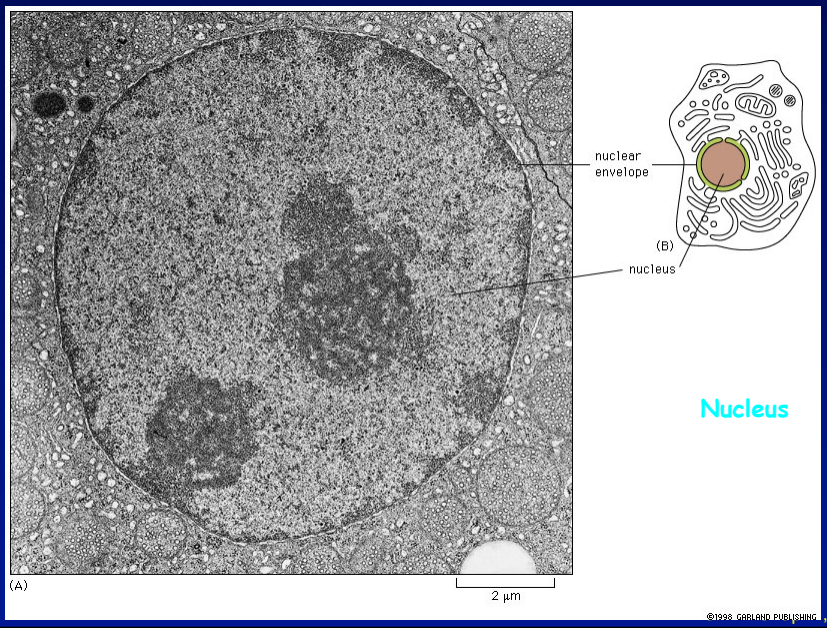
Organelles – Molecular factories



Macromolecular assemblies – molecular machines

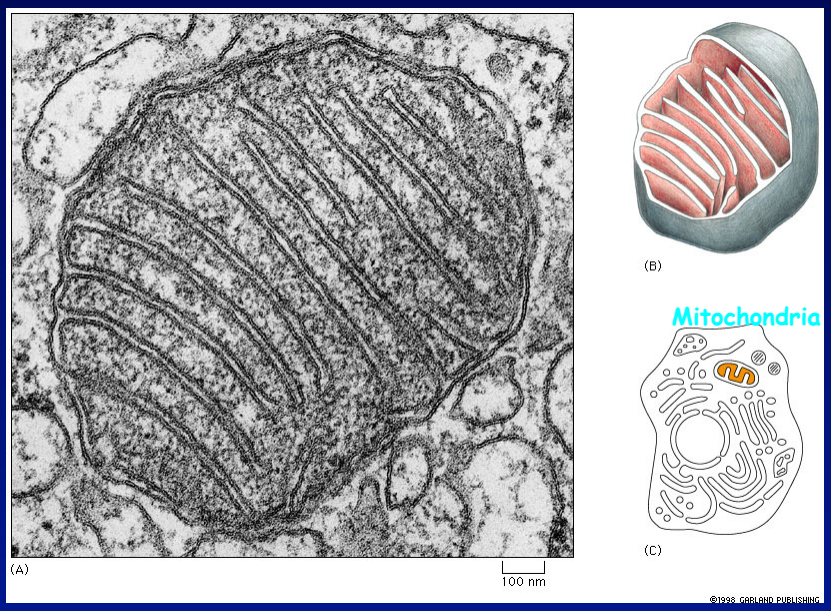


Information storage and processing



Nucleus

Energy production



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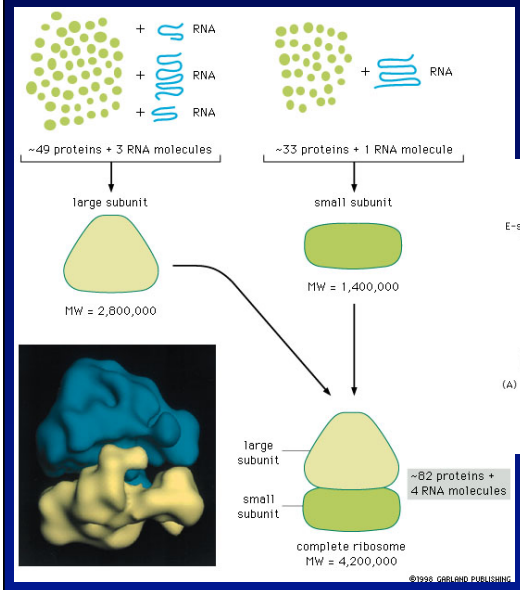
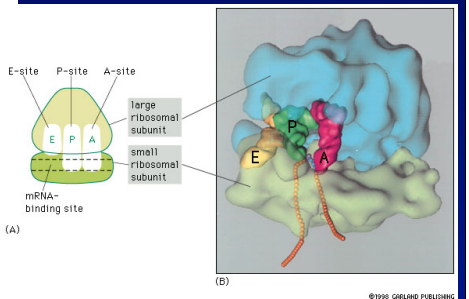
Ribosome





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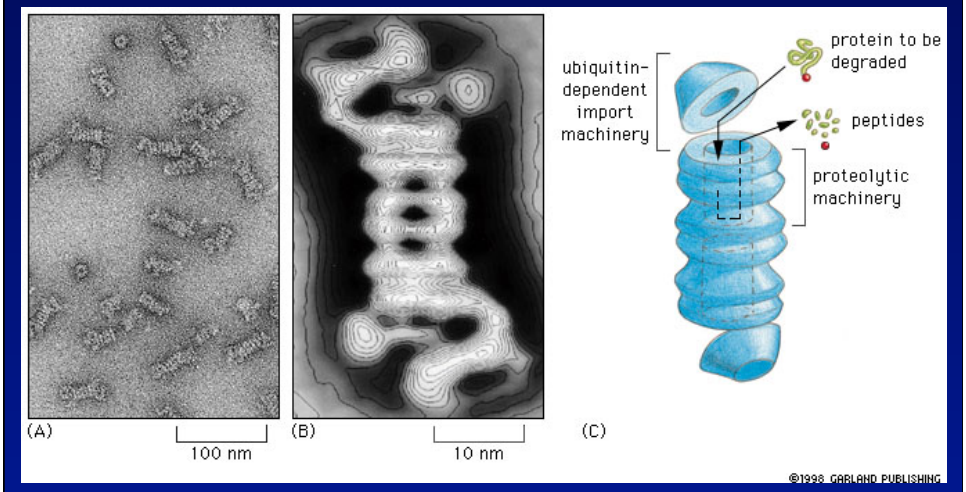
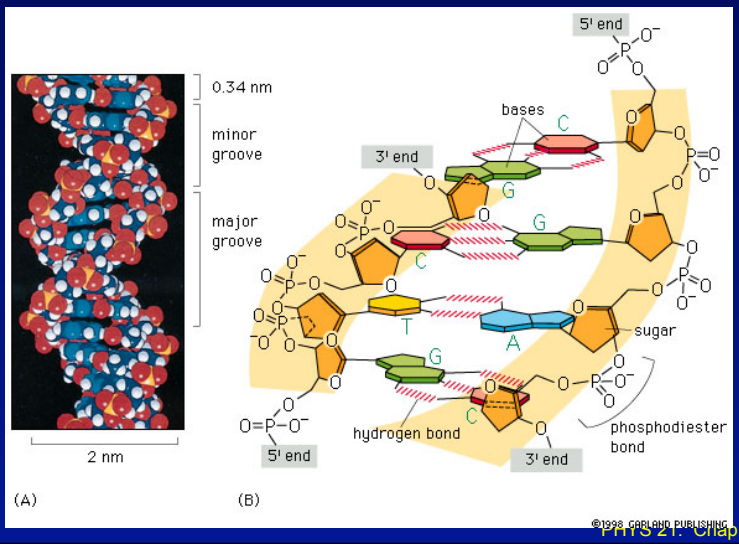
Proteosome
=
Peroxisome



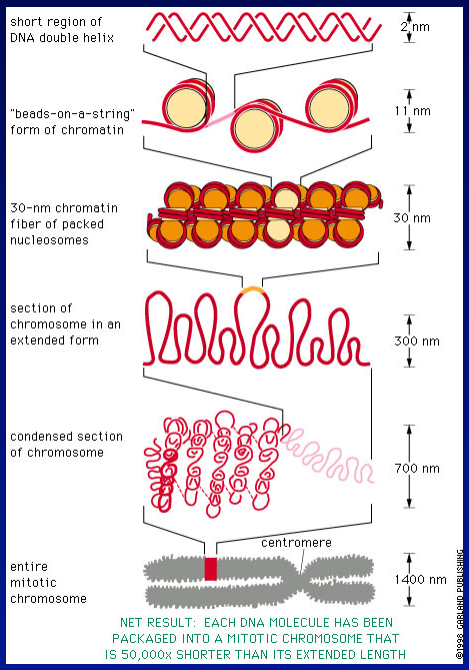
Macromolecules

"The two great polymer languages…" F. Crick

DNA



NUCLEOSOME



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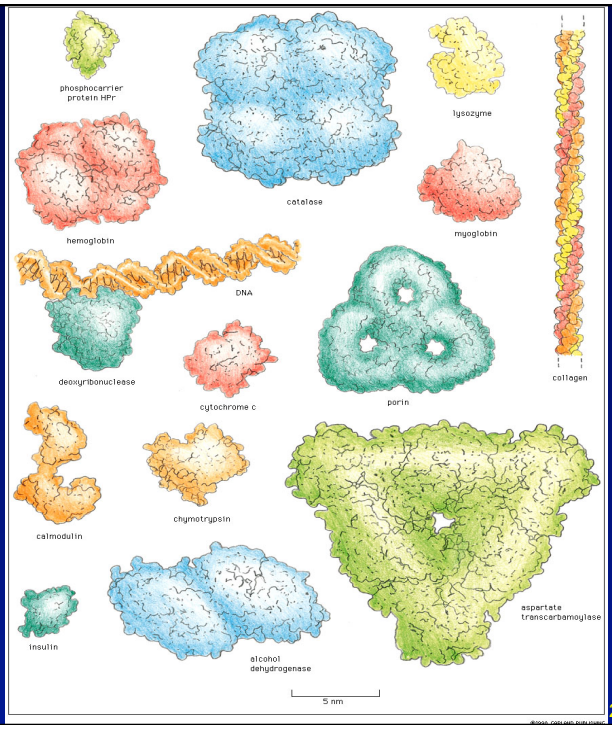
Proteins



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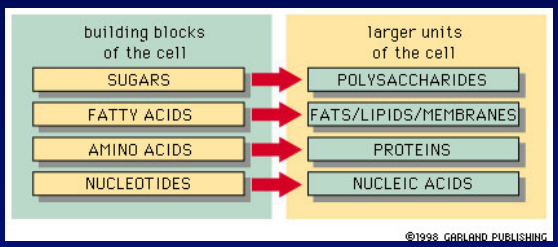
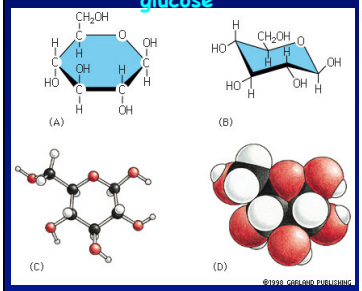
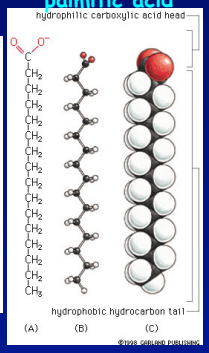
Small molecules



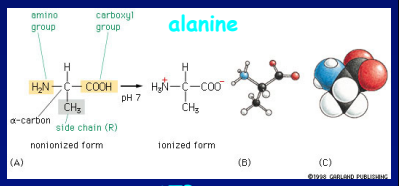
glucose



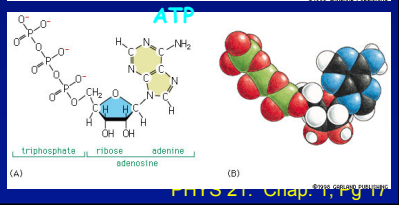
palmitic acid



alanine



ATP



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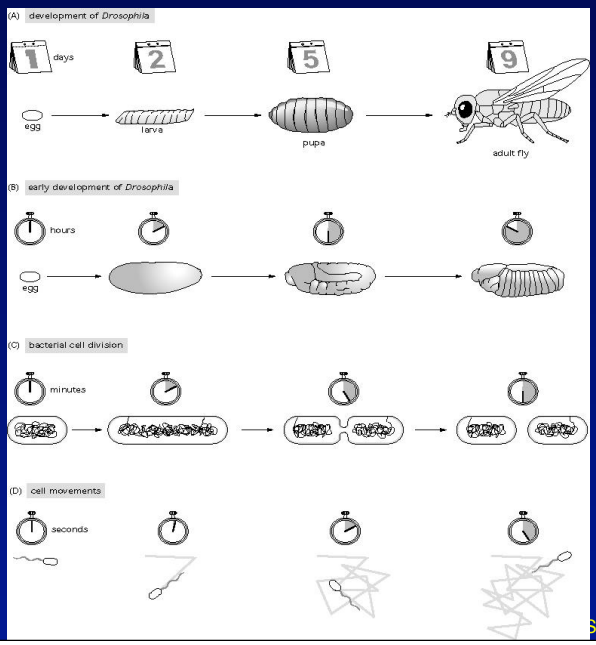
Hierarchy of temporal scales



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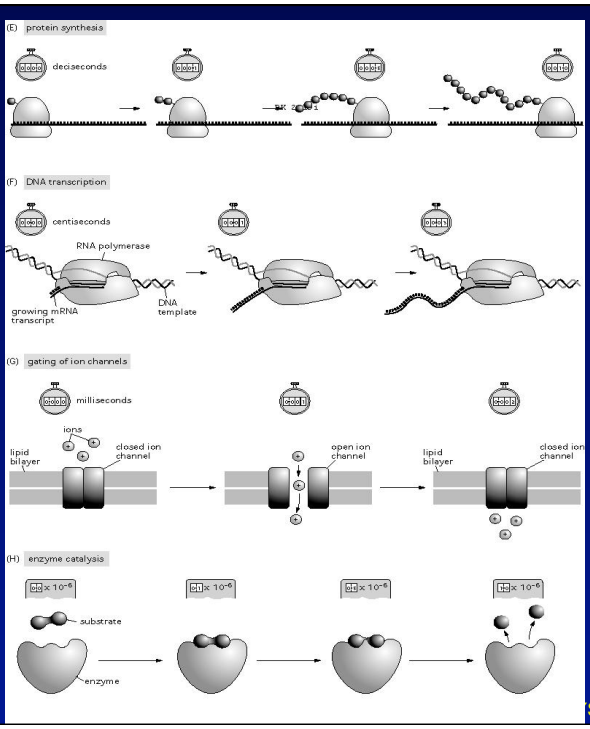

ConcepTest 2.1a How heavy is it

What is the mass of a gallon of milk?

1. 1 kg
2. 5 kg
3. 25 kg
4. 100 kg
5. 1000 kg

ConcepTest 2.1a How heavy is it

What is the mass of a gallon of milk?

1. 1 kg
2. 5 kg
3. 25 kg
4. 100 kg
5. 1000 kg

A pint's a pound the world around – from my mom. 1 gal = 4 quarts = 8 pints → 8 lbs = 5 kg

ConcepTest 2.2a How heavy is it

Your aquarium is 1 m^3 … you must love fish or else be a doctor. How much does it weigh when filled with water

1. 10 kg
2. 100 kg
3. 1000 kg
4. 10000 kg
5. 100,000 kg

ConcepTest 2.2b How heavy is it

Your aquarium is 1 m^3 … you must love fish or else be a doctor. How much does it weigh when filled with water

1. 10 kg
2. 100 kg
3. 1000 kg
4. 10000 kg
5. 100,000 kg

Remember water's density is 1 g/cm^3. There are 100 cm/m or 10^6 $(cm/m)^3$. 10^6 g = 1000 kg

Ponderable

You are thinking about transferring to another university, but your parents are not very supportive. How many days will it take to walk from GW to the University of Chicago?

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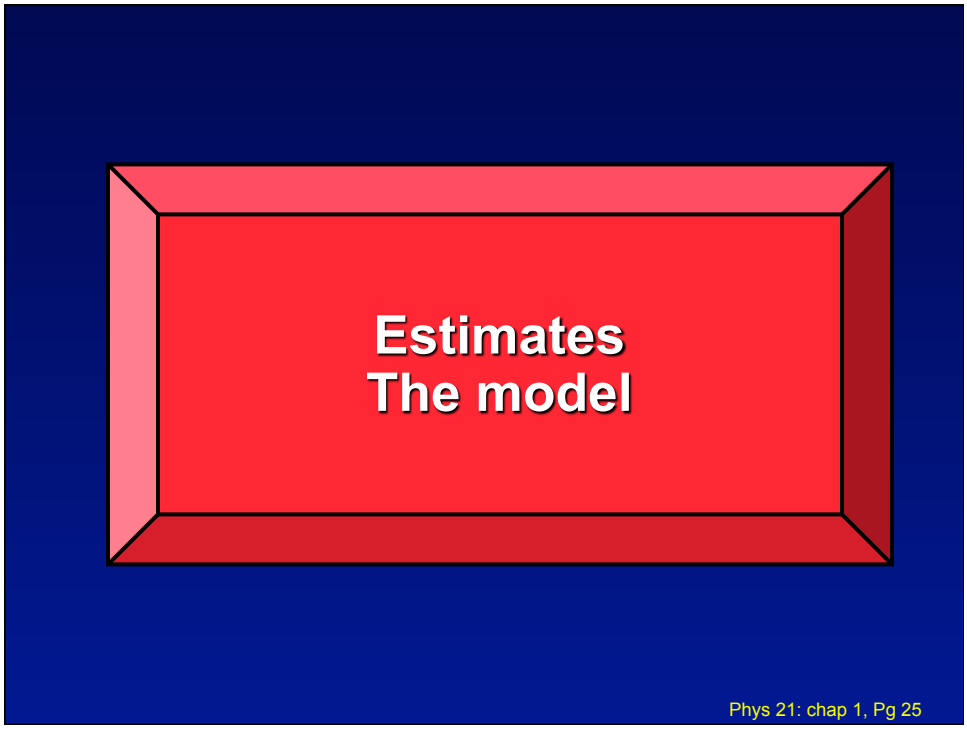

You need some idea of how things work

To stay sane, you need to have a simple model and some simple rules. For example

- Most living things are made of water
- Arms are cylinders, proteins are spheres
- d = vt
- Things move between 1 and 10 body lengths per second (think Olympic sprinters)
- Things scale, imagine ant-sized olympic sprinters
- Off by a factor of 2 no problem, you are sane
- Off by a factor of 10, big problem, you are insane

What if you are off by a factor of 10 or more?

- Your math is wrong ... No excuse
- Your model makes no sense … need to study
- Your model is missing something essential … you may have made a discovery.

Example

What is the mass of your arm?

Ponderable

What is the density of an eColi cell?

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