SMS 303: Integrative Marine Sciences III

- Instructor: E. Boss, TA: A. Palacz

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Office hours upon appointment (free after class).

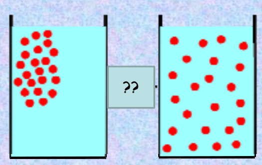
Expectation: be involved, ask questions, do the reading and assignments (on time), provide feedback.

- 5 weeks & topics: diffusion, mixing, wave, tides and Coriolis.

Class web site:
http://misclab.umeoce.maine.edu/boss/classes/SMS_303/SMS303.htm

- Diffusion
  - A collaborative exercise in class and corridors.

Short introduction:



•Diffusion in marine sciences.

•Fick/Fourier's laws.

•Differential equations are the needed math (what are these?).

•Macroscopic and microscopic descriptions.

•Diffusion and order are linked (Entropy).

•Irreversible without investment of energy.

- Diffusion in marine sciences

Examples of processes diffusion is important for:

•Nutrient uptake by phytoplankton and bacteria.

•Dissolution of particles.

•Exchange of solutes in sediment pore waters.

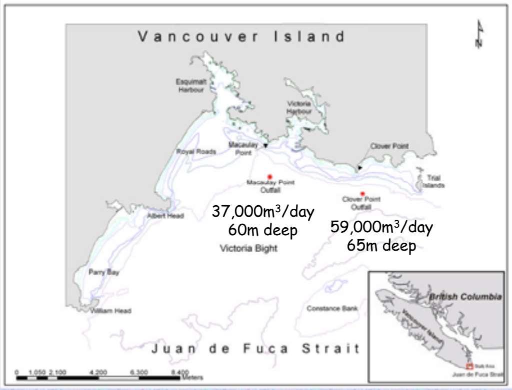
•Exchange of solutes within multi-cellular organisms.

•Gas diffusion is important for diving physiology.

•Release of waste products.

•Double diffusion.

The story of Victoria, BC (Population: 350,000+3M visitors):



Since 1894: 'The solution to pollution is dilution…'

Why was nothing done so far (plans ARE under way):

Don't flush sewage dollars

Poisonous chemicals are the real culprits

We don't blush when we flush

Despite its concern for the environment, Greater Victoria treats the strait like a toilet

Treating sewage bad for environment

Why do **you** think it may be an environmental problem:

Mr. floatie

Contains:
- Nutrients
- Organic material
- Pathogens
- Medicines
- Cleaning products
- Pesticides

Maine has its share of polluters:

NYTimes story
(http://projects.nytimes.com/toxic-waters/polluters/maine)

How are pollution and diffusion linked?

Diffusion in a homogeneous fluid:

Fick's and Fourier's laws – down-gradient flux of material and heat.

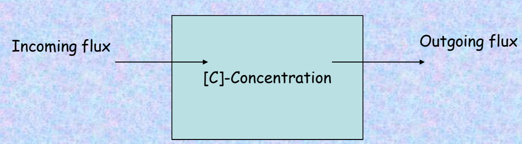
Friction – down-gradient flux of momentum.

flux = -diffusion coefficient x gradient {e.g. [moles/s/m^2]}

In 1-dimension: $F=-Dd[C]/dx$

What are the units of the diffusion coefficient?

Same units (not value) for momentum, temperature and scalars.



In 1-dimension: $\partial[C]/\partial t = -\partial F/\partial x = D\partial^2[C]/\partial x^2$

A **differential equation** is a mathematical equation for an unknown function (e.g. temperature) of one or several variables (e.g. time and space) that relates the values of the function itself and of its derivatives of various orders (Wikipedia).

An ordinary differential equation (ODE) is a differential equation in which the unknown function is a function of a *single* independent variable.

A partial differential equation (PDE) is a differential equation in which the unknown function is a function of *multiple* independent variables and their partial derivatives.

What kind of equation is:

In 1-dimension: $\partial[C]/\partial t = D\partial^2[C]/\partial x^2$

Answer: a 2nd order in space 1st order in time PDE.

Some analysis of the diffusion equation:

$$\partial[C]/\partial t = D\partial^2[C]/\partial x^2$$

What is the characteristic time scale in takes a molecule to diffuse a distance L?

Is this equation symmetric in time (invert t with –t)?

The concept of entropy (log of probability of state).

The 2nd law of thermodynamics.

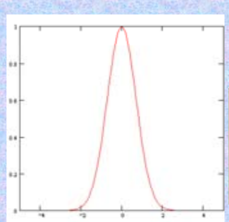
Diffusion and entropy.

Boundary and initial conditions

http://somoselequipotres.blogspot.com/2007/11/law-of-increasing-disorder.html

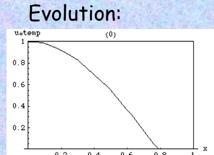
The macroscopic view of diffusion (continuum):

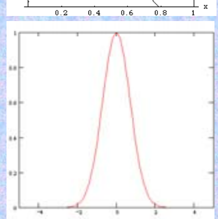
Initial condition:

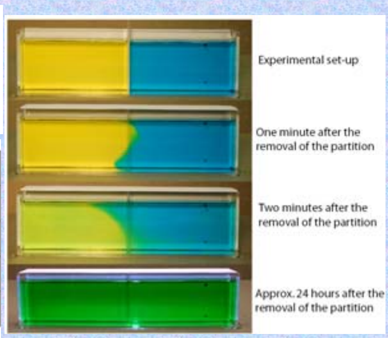


http://galileo.phys.virginia.edu/classes/311/notes/dimension/node8.html

The macroscopic view of diffusion (continuum):
Evolution:







http://galileo.phys.virginia.edu/classes/311/notes/dimension/node8.html

The microscopic view of diffusion:

Rather than a continuum, the material is thought of as being comprised of discreet entities (molecules). The statistics of the molecular motion result in the macroscopically observed properties (concentration, temperature, momentum).

Molecules move randomly in the material. A dissolved substance introduced at one side of a tank eventually spread throughout it (diffusion of material).

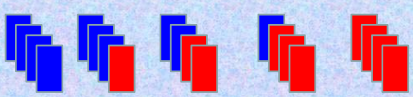
Molecule bumping into one another transferring energy (mean kinetic energy) and momentum (resulting in diffusion of temperature and momentum).

Some applets

http://www.biosci.ohiou.edu/introbioslab/Bios170/diffusion/Diffusion.html

Class simulation 1:

time=0

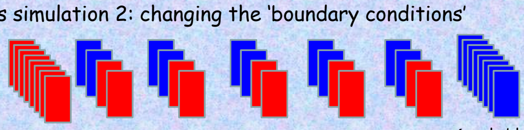


Rule: at each time step each student exchange one RANDOM cards with his/her neighbors.

Prediction: what will be the average concentration after 1 step? 2 steps? 10 steps?

Class simulation 2: changing the 'boundary conditions'

time=0



only red →

← only blue

Start with the same cards you finished the last simulation with.

Rule: at each time step each student exchange one RANDOM cards with his/her neighbor. The students at the ends simply put one card at the end and take the color associated with that end.

Prediction: what will be the average concentration after 1 step? 2 steps? 10 steps?

What is the difference between the two simulations?

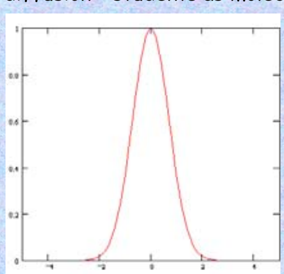
How is the final state related to the solution of the diffusion equation?

In 1-dimension: $\partial[C]/\partial t = D\partial^2[C]/\partial x^2$

Questions:

1. How does the final condition depend on the initial condition?
2. For given boundary conditions what is the steady state solution of $\partial[C]/\partial t = D\partial^2[C]/\partial x^2$?
3. How is flux affected?
4. How would increasing temperature affect D?

Simulation 3: diffusion – students as molecules



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How can we describe the changing concentration distribution as function of time?

Simulation 3: diffusion

Description of activity:

1. All student stand in line(s) of tile.
2. Every turn(1-16) toss a coin and move one tile left (head) or one tile right (tail). Note: a turn=time step.
3. Record your tile position (number) at each time step.
4. One student in each group will record the data of the number of students at each tile which will be posted on-line for analysis as part of your homework.

Simulation 4: biased diffusion

Description of activity:

1. All student stand in line(s) of tile.
2. Every turn (1-16) toss a coin and move left one tile (head) or right TWO tiles (tail).
3. Record your tile position (number) at each time step.
4. One student in each group will record the data of the number of students at each tile which will be posted on-line for analysis as part of your homework.

Other related processes:

Brownian motion:

Brown was studying pollen particles floating in water under the microscope. He then observed minute particles within the vacuoles of the pollen grains executing a jittery motion. By repeating the experiment with particles of dust, he was able to rule out that the motion was due to pollen particles being 'alive', although the origin of the motion was yet to be explained.

[Brownian motion applet](http://galileo.phys.virginia.edu/classes/109N/more_stuff/Applets/brownian/brownian.html):
http://galileo.phys.virginia.edu/classes/109N/more_stuff/Applets/brownian/brownian.html

Biased random walk:

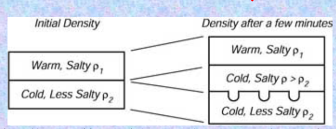
Osmosis:

[Osmosis applet: http://www.eeb.uconn.edu/people/plewis/applets/Osmosis/osmosis.html](http://www.eeb.uconn.edu/people/plewis/applets/Osmosis/osmosis.html)

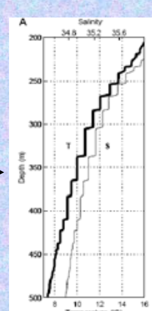
Double diffusion- $D_{temperature} \approx 100 \times D_{salt}$.

1.5×10^{-7} m²/s vs. 1.3×10^{-9} m²/s

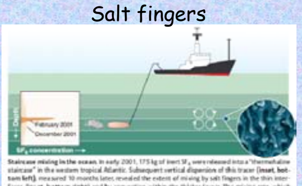
Class experiment

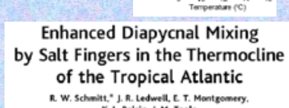


http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html



Salt fingers





Enhanced Diapycnal Mixing by Salt Fingers in the Thermocline of the Tropical Atlantic

R. W. Schmitt,* J. R. Ledwell, E. T. Montgomery, K. L. Polzin, J. M. Toole

SCIENCE VOL 308 29 APRIL 2005

Vertical eddy diffusion~ 0.9×10^{-4} m²/s

Summary comments:

Diffusion is responsible for a net *down-gradient* transport of solutes and heat and is the *only* process that can irreversibly mix.

It results from microscopic atomic 'behavior' and has macroscopic consequences.

Living cells rely on diffusion to obtain nutrients and get rid of waste products.