SMS-204: Integrative marine sciences.

Course mechanics:

Instructors: Jim Loftin and Mary Jane Perry. Each teaches a different module (Physics and Chemistry).
Meeting times: Monday 12:10-1pm class + lab modules.
Anybody needing special assistance with the class (e.g. learning disabilities, problems in accessing the facilities) please come see me.
Web site for physics module:
http://misclab.umeoce.maine.edu/boss/classes/SMS_204/syllabus.htm

Expectations in class: I expect you to listen and interact. If you don't understand a topic discussed please raise your hand and say so. If you don't, I will assume that you understand the material and charge ahead. This class is yours and for you. Take advantage to learn as much as you can and do not hesitate to stir the class discussion in directions that interest you.

Expectations out of class: Read the readings posted on the class's web site for both previous classes and the upcoming one. I may give a quiz in class to assess how much was learned from the readings. Reading out of class will provide us with more time in class to spend on discussions, demonstrations, and to get deeper into the implications of the facts and concepts we learned from the readings.

Grading: Grading in the physics module will be based on participation (20%, including on-time arrival to class), weekly assignments and quizzes (50%) and a final exam (30%). Late assignment will suffer an automatic 10% decrease in the grade for this assignment (if late by more than a week later, the grade will be zero). The homework will cover class and lab materials as well as reinforce skills needed for future classes. I strongly encourage you to work on them in groups. Groups can achieve significant learning experiences as students debate their views of the problem solved. Hand in individually written (or typed) homework (the homework should NOT be identical). Identical or nearly identical homework will not receive more than 50% of the maximum grade for the assignment and will be subject to disciplinary action under University of Maine policies on plagiarism.

Class materials: Class notes are posted on the web before class (at least a week ahead). I will underline concepts that I want you to learn and expect you to understand. The notes are provided "*as is*" without any guarantee. I may find typos in them that I will correct on the web or mention in class (last date of revision is available on each page). I (and Pete Jumars) spent a lot of time developing these pages and am posting them on the web for the benefit of the class in particular and the academic community in general. I added the copyright logo (©) so that people will not simply copy these notes and produce a book from which they will derive a profit. I expect users of these notes to provide acknowledgment when due and would appreciate any feedback so as to improve them. The reference list provided at the end of the reading materials for each lecture is not required reading material. It is given so that those interested can get deeper into a subject presented in class. Web links for other material relevant for the class are found at the class website.

Lecture 1:

Topic 1: Why study physics if you are interested in marine biology?

Four defining activities of living organism are: acquiring food, reproducing (e.g. finding a mate), evading predators and getting rid of waste products (Eric Schulenberger, personal communication). These traits are tightly coupled to the physics of the environment inhabited. For example: 1. Sound propagates very well in water (and potentially much further than light) and indeed we find a lot of organisms using sound in the ocean. 2. Specific swimming behaviors have different energetic requirement that change with organisms' size; micro-organisms that swim do not swim at all like fish. 3. Sensing the presence of a predator around an organism can be based on sight, sound, and pressure perturbation, in ways that are very different from organisms on land. 4. Many marine organisms are filter feeders; the design of a good filter is not obvious unless you understand the physics of the fluid on the scale of the organism. We all live under physical constraints; physics and biology don't operate in separate worlds.

Through time organisms have evolved many adaptations to the marine environment. It is a standing puzzle for us to understand how the richness of aquatic organism strategies for mating, evading predator, acquiring food and getting rid of waster products relates to their environment.

Topic 2: Dimensions and Units

There are a few fundamental dimensions in physics. By fundamental I mean that other physical quantities of interest have dimensions that can be built using the fundamental ones. We will use:

Time [T],
Length [L],
Mass [M].

Example of non-fundamental (derived) dimensions are:

Area-$[L^2]$,
Density (= mass/volume) = $[M/L^3] = [M\ L^{-3}]$,
Velocity = $[L\ T^{-1}]$.

Knowledge of dimensions is vital in physics. Any relationship between physical variables has to be consistent in terms of dimensions (i.e., both sides of an equation should have the same dimensions). This kind of consistency is called dimensional homogeneity.

Units: the tick marks on different rulers all describe the dimension of length but may do so differently. The size of a legal lobster (a keeper) is 6 inches, which is approximately 20 cm. If it were 6 cm, there wouldn't be many left... It is important to be consistent with units. Most scientists have adopted an international standard called 'System International' (SI), which we will strive to use in this class as well. Sometimes, I slip into a closely related system (cgs for centimeters, grams and seconds) because it may prove more intuitive. For a given problem, correct answers will result only if you stay within a single, consistent, set of units for both primary and derived dimensions.

Table 1: Physical quantities, their associated dimensions and SI units.
From primary mks (SI) units, we derive other units as shown in the table below (following Vogel, 1994, with some changes in notation):

Quantities (notation)	Dimensions	SI Unit (notation)
Length, distance (l)	L	meter (m)
Area, surface (A)	L^2	square meter (m^2)
Volume (V)	L^3	cubic meter (m^3)
Time (t)	T	second (s)
Velocity, speed (v)	LT^{-1}	meter per second ($m\ s^{-1}$)
Acceleration (a)	LT^{-2}	meter per second squared ($m\ s^{-2}$)
Mass (m)	M	Kilogram (kg)
Density (ρ)	ML^{-3}	Kilogram per cubic meter ($kg\ m^{-3}$)
Force, weight (F, W)	MLT^{-2}	newton (N or $kg\ m\ s^{-2}$)
Work, Energy (W, E)	ML^2T^{-2}	joule (J or N m)
Power (P)	ML^2T^{-3}	watt (W or $J\ s^{-1}$)
Pressure, stress (p, τ)	$ML^{-1}T^{-2}$	pascal (Pa or $N\ m^{-2}$)
Dynamic viscosity (μ)	$ML^{-1}T^{-1}$	pascal second (Pa s)
Kinematic viscosity, Diffusivity (ν, D)	L^2T^{-1}	square meter per second ($m^2\ s^{-1}$)
Surface tension (γ)	MT^{-2}	newton per meter ($N\ m^{-1}$)
Salinity (S)	Dimensionless	Related to mass of solutes/mass of solution.

In some cases physical quantities do not have dimensions*:

Quantity (notation)	SI Unit (notation)
Temperature (T)	Degrees Kelvin (K)

*Temperature is proportional to the average kinetic energy of molecules [J] through a constant (Boltzman's constant, k, [$J\ K^{-1}$]). We'll deal again with it in a future class.

Topic 3: Coordinate system, and some basic notation

In this course we will adopt a Cartesian coordinate system. Every point in space is described by three coordinates (x_0,y_0,z_0). In addition, if we want to identify any point an organism occupies along a trajectory, we need the time t_0.

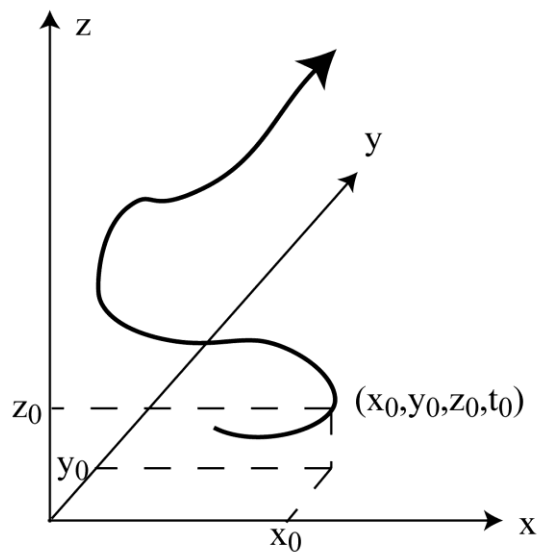

Fig. 1. A trajectory in space and time. Each point along the trajectory is identified by its three spatial coordinates and the time when it was there.

The shortest distance between two points (x_0,y_0,z_0) and (x_1,y_1,z_1) is given by:

$$L = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2}\ .$$

The velocity vector is given by:

$$\vec{V} \equiv (u, v, w) = \left(\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt}\right),$$

where a derivative means:

$$\frac{dA}{dx} \equiv \lim_{\Delta x \to 0} \frac{\Delta A}{\Delta x}\ .$$

When a quantity depends on more than one variable, the derivative with respect to any one variable (the 'partial' derivative) is denoted with the '∂' symbol.

Force, position, acceleration and velocity are the vectors we will work with. All other quantities of interest to us are scalars; they have a magnitude by no direction (can be described by a single number, for example temperature).

Topic 4: Measurements, precision, and accuracy

There is no such a thing as a physical measurement without an uncertainty (sometimes referred to as an error). Uncertainty may be due to the finite precision of our measuring device (e.g., the tick marks on a ruler). For example, when I last checked, my height was 1.78 ± 0.01 m (on a good-hair day). ±0.01 represent a measure of uncertainty. We will develop several such measures.

Precision denotes the reproducibility of the determination of a quantity. Accuracy denotes the ability to measure the "true" value of a quantity. A measuring instrument may be precise but not accurate if it hasn't been calibrated for a while. That is, one can be precisely wrong. Conversely, a crude instrument may be accurate but imprecise. Both precision and accuracy are relative; that is, they depend on the values and intent of the beholder. What may be acceptable for a measurement for a certain purpose may not be acceptable for another (e.g., while knowing my height within 1 cm may be good enough to buy a baseball uniform, 1cm precision is not sufficient to fit me with glasses).

When we deal with natural systems and turbulent flows, quantities are rarely constant but rather tend to vary around a central value. In this case the average (or median or mode) of a quantity will be given (and specified) as well as some measure of the spread around it (e.g. standard deviation, x% confidence interval).

We often do not measure directly a quantity of interest. For example rather than measure the mass of an object we measure its weight (its mass times the gravitational constant).

Topic 5: Basic statistics

Statistics is a basic tool used to describe and analyze data. When we make measurements we often observe variability in the quantities we measure when we repeat the same measurement. Variability may be due to changes of the property measured (say the typical size of an adult salmon) or changes in the measurement tool. In order for us to gain some confidence in the measured representation of reality, it is important that we repeat the measurement. Repeating the same measurement enough times allows us to describe the probability distribution function for our measurement. For example, suppose that we were interested in the lengths of adult trout. We would go to the field and measure a whole bunch of them (say 1000). Plotting a histogram (number of fish of size between L and L+dL) we may get something like Fig. 2.

Although we could present the data to the reader of a report as a table or figure, it is often informative (and economical) to describe only a few summary characteristics of the above distribution. For example, it is informative to know the average size of an adult fish (to know if the one we got is larger than average) and the spread around that average (to know whether most fish fall close to or far from the average size).

The average (or mean) is simply computed by summing all the observations and dividing it by the number of observations:

$$\langle x \rangle = \sum_{i-1}^{N} x_i \quad .$$

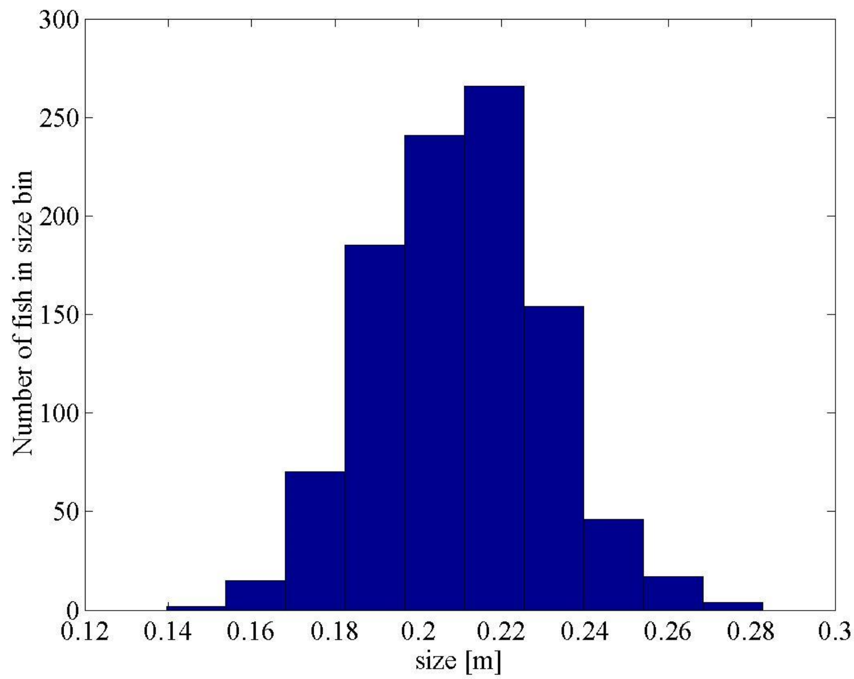

Fig. 2. A hypothetical histogram of the length of adult trout in a lake. Sample size, 1000.

The spread around the average is often quantified using the standard deviation:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i-1}^{N}\left(x_i - \langle x\rangle\right)^2}.$$

For example, for the data in Fig. 1, <x>=0.21m and σ=0.02m. These statistics provide very useful information when we know something about the underlying distribution function. For example, if the distribution is *normal*, the average is also the median (i.e. there are as many larger fish as smaller fish relative to the average) and about 68% of the fish lengths are within 1 standard deviation from the mean (95% within 2 standard deviations).

When the underlying distribution function is unknown (or does not look like any distribution we know something about) a generally better (less sensitive to the shape of the distribution) estimate of central tendency in the data is the median of the distribution (i.e. the size of the fish for which half the population is larger and half is smaller). In order to quantify the spread around the median we use percentiles; For example, the 10th percentile for which 10% the population is smaller and 90% are larger. The distance between the 10th and 90th percentile describe the spread encompassing 80% of the data. The mode of a distribution is the value which occurs most frequently. Its location depends upon the size of the bins (0.05m in Fig. 2) but also on the locations of the boundaries of the bins. Would the mode be the same if the bins started at zero instead of 0.025m?

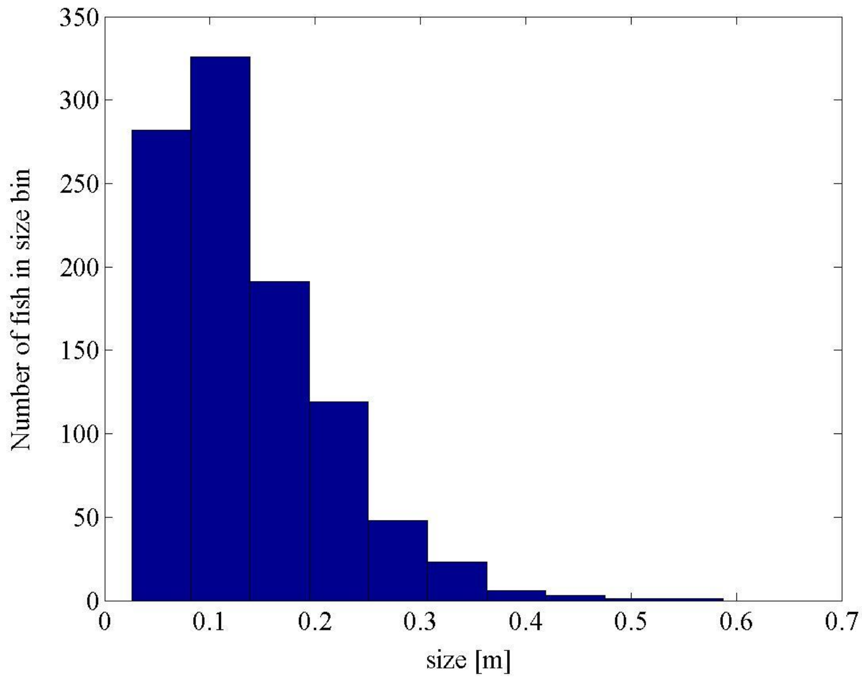

Fig. 3. Another hypothetical histogram of the length of adult trout in a lake. Sample size, 1000.

The fish in Fig 3. and Fig. 2 have the same average size (0.21m). However, the median of the population in Fig. 2 is 0.175m, significantly less than that of Fig. 1 (0.2 m). The standard deviation of the new distribution is σ=0.085m. The mode is 0.1.

Statistics is a branch of mathematics. In statistical analysis of the most common sort, all data points are considered equally informative and independent. In order to assure that treatment, we do not dismiss a datum (say, because it does not fit our hypothesis) unless we have very good grounds for doing so (we discovered a faulty connection in the instrument used to get the data). The need for independence of data to gain reliable information on variability means that we do not measure the same fish again and again when studying the population. Similarly, two measurements of temperature can be considered independent if they were done far enough apart in space or time. Having many data collected quasi-simultaneously does not mean that we have a good representation of the distribution of the property under consideration. A good distinction to keep in mind is the target population (the one to which we would like to generalize) and the sampled population (the one from which we sampled). Unless the two correspond in known fashion, generalizations are not likely to be valid.

Topic 6: Fluids and Solids

The main distinction between fluids and solids is in our ability to deform them (change their shapes). Although solids hold their shapes, fluids cannot. Fluids are further divided into gases that fill whatever container we put them in and liquids that do not. A solid can be held from its edge, a fluid cannot. In solids the molecules support each other. The support of fluids is provided by the container that they are in.

For a solid, the deformation (the angle θ) is dependent on the force per unit area (stress) that we apply (even if we cannot see the deformation by eye). This response is similar to the extension of a spring; the more force we apply the more the deformed the solid become (equivalent to the elongation of a spring under load).

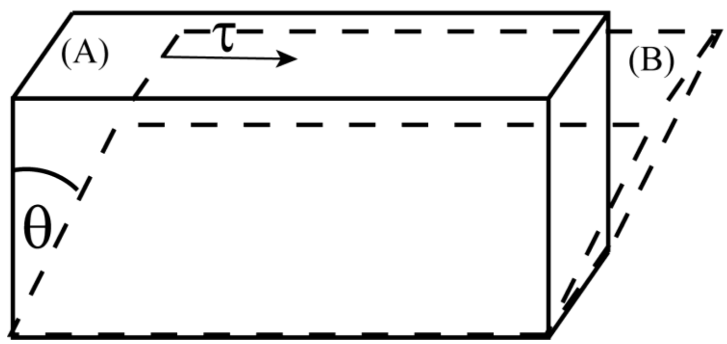

Figure 4. A deforming slab (from position A to B) under the action of a shearing stress (τ, force per unit area, applied parallel to the surface).

Fluids on the other hand can be distorted and are oblivious to their shape past or present. Fluids care about how *rapidly* they are deformed (the deformation rate).

These differences are summed up in the following mathematical relationships:

For solids: $\tau = G\theta$ (G is called the shear modulus).

For fluids: $\tau = \mu d\theta/dt$ (μ is called the dynamic viscosity, and is roughly constant for most fluids with which we are interested, i.e., air and water). Strictly, this equation holds only for small angles, θ, and short time, t. Note that for small θ, $d\theta/dt=dU/dz$, the change of horizontal velocity with depth, and that for all θ, $\tau = \mu dU/dz$. A fluid for which there is proportionality between stress and shear is called a "Newtonian fluid". Non-Newtonian fluids include dense suspensions of corn starch (‘ooblek’) for which apparent μ goes up with τ.

If the force per unit of area parallel to the face of a solid object is kept constant, its deformation (strain) will be constant (through constant G above). If the force per unit of area applied to a fluid is kept constant, its strain rate will be constant and proportional to μ.

Topic 7: Continuum hypothesis.

We treat fluids as a continuum (infinitely distortable and divisible) rather than as an ensemble of individual particles (molecules) with large spaces in between. This approach simplifies a lot the physical descriptions of fluid; instead of describing $6 \cdot 10^{29}$ individual molecular trajectories per m^3, we deal with a fluid entity whose smallest scale of interest is much larger in size than the individual molecules. It is convenient to replace the real fluid with a continuous physical model. Its properties represent the average behavior of the molecule (in density, temperature and viscosity).

Topic 8: No-slip condition.

Fluid sticks to solid surfaces at the molecular level. To some extent, the effect is due to molecular-scale roughness. No matter how carefully prepared, the surface still has bumps that are large with respect to the size of a water molecule. The energy lost through viscous dissipation as a fluid passes over and around these bumps is sufficient to ensure that it is effectively brought to rest. This assertion is true no matter how rough or smooth a surface is or whether it was lubricated with a hydrophilic substance (e.g., oil). An example of the consequences is that when you stir coffee or tea in a cup, eventually all the fluid comes to rest. A further factor increasing the resistance to flow at a surface is the polarity and asymmetry of water. The molecule looks like a head (O) with to Mickey mouse ears (H). The end with the ears carries positive charge. Resultant hydrogen bonding raises μ over what would happen without it and also the extent to which water sticks to solid surfaces.

The no-slip condition implies that a fluid flowing along a stationary solid, experiences shear, i.e., the velocity has to change from a non-zero value away from the interface to zero at the interface. Shear is the change of the velocity along a different axis than the axis of flow (in this case the change is in horizontal velocity with depth, Fig. 5).

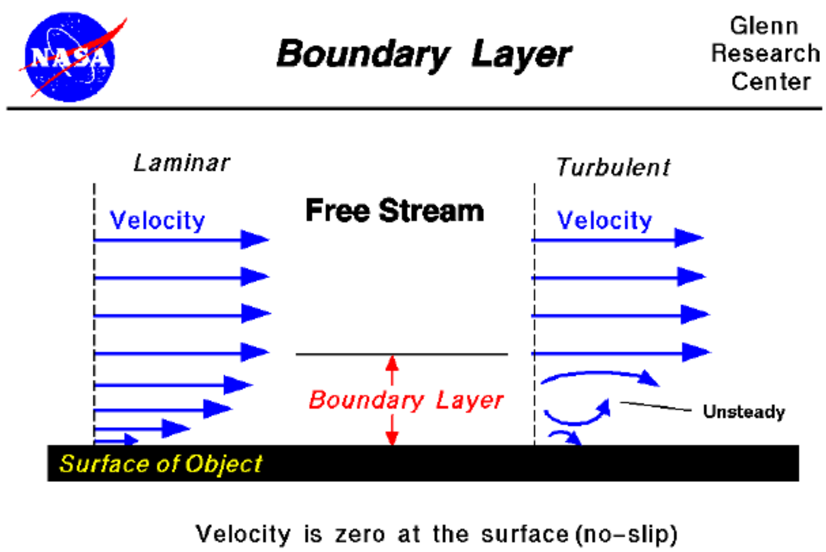

Figure 5. Due to the no-slip condition, the velocity next to an interface has to match the velocity of that interface (at rest in the figure). Since there is a flow above the interface, the flow velocity (U) is decreasing as we near the interface (where U=0). Thus there is shear, $dU/dz \neq 0$. For this situation, note that $\tau = \mu dU/dz$ *(from:* http://www.grc.nasa.gov/WWW/K-12/airplane/boundlay.html*)*

Topic 9: Air vs. water.

Air and water are two fluids we need to learn about in order to understand the behavior of marine organisms. Below is a table comparing properties of air and water of importance for the next few lessons:

Table 2. Comparison of properties of air and water. Based on Denny, 1993.

Property	Air (Dry, on ground)	Water (surface)
Density, ρ, [kg m^{-3}]	$1.13 \rightarrow 1.29$ (from 40°C to 0°C)	$1000 \rightarrow 1028$ (from 0 to 35psu) Temperature effect < 5%
Dynamic viscosity, μ [N s m^{-2}]	$1.72 \cdot 10^{-5} \rightarrow 1.91 \cdot 10^{-5}$ (from 0°C to 40°C)	$0.65 \cdot 10^{-3} \rightarrow 1.79 \cdot 10^{-3}$(from 40°C to 0°C), Salinity effect < 10%
Kinematic viscosity, $\nu=\mu/\rho$, [m^2 s^{-1}]	$1.33 \cdot 10^{-5} \rightarrow 1.7 \cdot 10^{-5}$ (from 0°C to 40°C)	$0.66 \cdot 10^{-6} \rightarrow 1.79 \cdot 10^{-6}$(from 40°C to 0°C), Salinity effect < 10%

Notice that the density of water is approximately one thousand times larger than that of air. Interestingly, the weight of the atmosphere per unit area is approximately the same as the weight of a 10m tall column of water. If the atmosphere were of constant density (which it isn't) how tall would it be?

References and additional reading:

Denny, M. W., 1993, Air and Water, Princeton U. Press, Chapter 1-3.
Vogel S., 1996, Life in moving fluids, Princeton U. Press, Chapter 1-2.

This page was last edited on 12/8/2015