8.298 Lies / Check your understanding

1 Wetting your feet

1.1 Estimate how many liters are in a barrel of oil and how many barrels of oil the United States imports every year.

1.2 The mass of the sun is $2 \cdot 10^{30}$ kg. Estimate the mass of earth and the ratio

$$\frac{\text{mass of sun}}{\text{mass of earth}}.$$

2 Scaling

2.1 How long is a year on Mars ($d \sim 2.3 \cdot 10^{11}$ m from the sun)

2.2 Imagine a long steel rod hanging under its own weight. How does the maximum length before it breaks depend on its cross-sectional area?

3 Dimensional analysis

3.1 What are the dimensions of power, energy flux, pressure, moment of inertia, and current, in terms of length L, mass M, time T, and charge Q?

3.2 The volume V of a pyramid depends on its base area A and its height h. How many dimensionless groups do the three variables V, A, and h produce? Find them and write a general formula of the form

$$\text{group containing } V = f(\text{other groups}).$$

3.3 An object (ring, disc, sphere, etc.) rolls down an inclined plane without slipping. List the variables relevant to finding its acceleration a down the plane [Hint: a, I (its moment of inertia), and m (its mass) are three variables.] Find a set of dimensionless groups and then write the acceleration in the form

$$\text{group containing } a = f(\text{other groups}).$$

If you double the radius of the object (e.g. use a big disc instead of a small disc), what happens to the acceleration?

4 Drag

4.1 Estimate the Reynolds number for a 747 and for a bumblebee.

4.2 Estimate the drag force on you while bicycling at 15 mph and the mechanical power required. How can you check whether this power is reasonable?

4.3 Estimate the terminal velocity of a $10\,\mu$m fog droplet and the Reynolds number. How can you check whether your terminal velocity is reasonable? Is the flow viscous or turbulent?

5 Mechanical properties

5.1 Estimate the energy to remove the final electron from He^+.

5.2 Stiffness and strength both have dimensions of pressure. How do they differ in physical meaning?

5.3 How long can a steel wire be before it breaks under own weight? Does this calculation use stiffness or strength?

5.4 Does the speed of sound in a material depend on its stiffness or on its strength?

6 Thermal properties

6.1 Estimate the mean free path of air molecules at room temperature and $p = 0.1\,\mathrm{atm}$.

6.2 What is the difference between κ (thermal diffusivity) and K (thermal conductivity), in dimensions and in physical meaning?

6.3 Estimate the ratio

$$\frac{\text{time to cool a hardboiled egg with } r = 2.5\,\mathrm{cm}}{\text{time to cool a hardboiled egg with } r = 2.0\,\mathrm{cm}}.$$

Does κ (diffusivity) or K (conductivity) determine the cooling times?

6.4 Estimate the diffusion constant for a random walk with step size of 2 m and interval between steps of 10 s.

6.5 The diffusion constant for water molecules in water (i.e. for a 'green' water molecule random-walking among the other water molecules) is $D \sim 10^{-9}\,\mathrm{m^2\,s^{-1}}$. How long does a water molecule take, typically, to diffuse the length of an Olympic swimming pool?