On force multipliers

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Warm-up problems

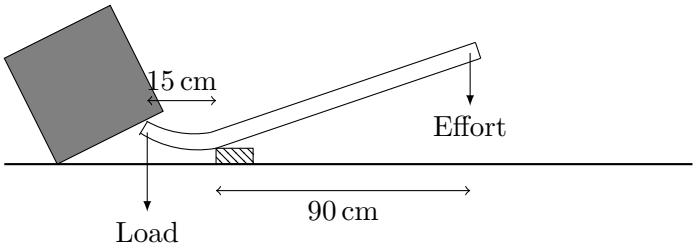
1. Draw simple diagrams to show how the *effort* force, *load* force and the *fulcrum* (or pivot) are arranged in the three classes of levers. Why are there only three classes of lever?

2. Give five examples of levers being used in everyday life. Make sure you include at least one of each class of lever, and preferably not ones from class!

3. Write down the definition of *pressure*. For a fluid inside a closed container like a balloon or syringe, where and in what direction is the force in the definition, and how does it arise (draw a diagram to show this)?

Regular problems

4. (a) Show that the effort force needed to raise the block using the lever below is only $\frac{1}{6}$ as big as the load force on the lever, and explain in your own words how this lever acts as a force multiplier.



   (b) The *mechanical advantage* of this lever is 6, as it can lift a load force 6 times that of the effort force. A paint tin can be prised open by using a 2p coin or a 15 cm long screwdriver. State which has the larger mechanical advantage, and make an estimate of the mechanical advantage of each in this situation (a suitable diagram will help you to do this).

   (c) Draw a simple diagram of the lever in your arm. By taking suitable measuremnents of your own arm, work out the effort force your bicep muscle has to exert to lift an apple of mass 100 g. Why do you think the arm is designed like this?

5. It is said[1] that Archimedes' work on levers lead him to boast "Give me a place to stand and with a lever I will move the whole world." This seems a fairly safe boast, since such a place (and such a lever) would not readily be forthcoming. The Earth is attracted to the Sun by a centripetal force of gravity of some 3.5×10^{22} N. If we use the Moon as a fulcrum, which is 384 400 km from the Earth, how long do you estimate the lever would have to be to bring the effort force required within the grasp of an ordinary human being?

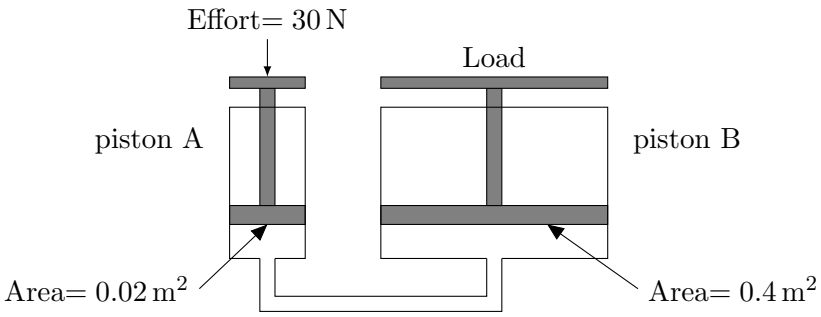
6. (a) Calculate the pressure of a 1 kg mass which has a base surface area of 100 cm^2 on a table.

[1] Pappus of Alexandria *Collection or Synagoge, Book VIII*, c. AD 340

(b) A fine filter paper can only withstand a pressure of $2.5\,\mathrm{N/m^2}$. Over what area must a gel with mass 800 g be spread so as not to rupture the filter paper?

(c) 200 m under the sea you can imagine that there is a column of water 200 m high pressing down on every $\mathrm{m^2}$. What will the volume of this column be, what will be its weight if the density of water is $1000\,\mathrm{kg/m^3}$, and thus what is the pressure at this depth?

7. In the situation shown below, an effort force of 30 N is used to lift a larger load of using a hydraulic system of pistons which acts as a force multiplier.



(a) Why is a liquid used in the pistons of this system rather than a gas?

(b) What is the pressure of the liquid in piston A (think about the pressure on the liquid from the piston face)?

(c) What load force can be raised on piston B (think about the pressure of the liquid on the piston face)?

8. In a similar hydraulic system, a load is to be lifted on 4 pistons, each of which have an area of $0.15\,\mathrm{m^2}$. If the pressure in the system must not exceed $3.0 \times 10^8\,\mathrm{Pa}$, what is the maximum load which can be lifted?

Extension problems

9. Levers and hydraulics seem to offer a magic way to increase the force we can push with. Even if we're not very strong, we can lift incredibly heavy weight forces with a suitable lever (just like Archimedes!) But surely there's a nagging doubt: we've already learnt that energy is always conserved (it can't be created or destroyed). So how can force multipliers work – aren't we getting something for nothing here?

10. A sailor often uses a different kind of force multiplier called a pulley, which is a wheel with a grooved rim, several of which are sometimes mounted in a block. The effort is applied to the rope which passes over the pulleys (the pulley shown below has a mechanical advantage of 2). Why is it that (if we neglect the effects of friction on efficiency) pulleys only come in certain ratios of mechanical advantage $(1, 2, \ldots)$ whereas levers and pistons can be made up to have any mechanical advantage required?