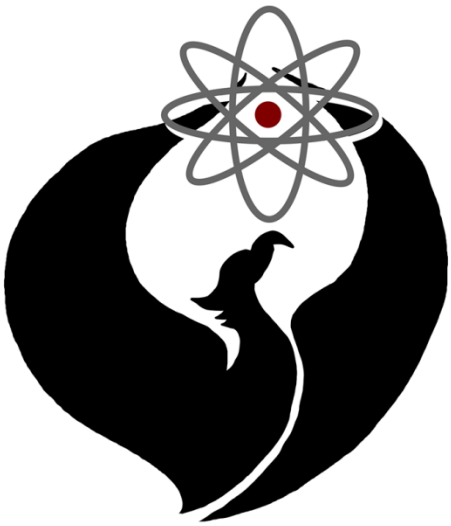
Machines B
Exam



University of Chicago Science Olympiad Invitational 2020

Saturday, January 18, 2020

1. Please **do not start** the test until told to!

2. Please **do not write on the test** unless the supervisor says it's okay to (the tests may be reused between blocks).

There are 9 questions in all, though some have multiple parts.

The emphasis of this test is not on significant figures, so three sig figs should be enough for every question (but no penalty for extra).

Some questions may ask for fractions, which you don't need to convert into decimals. However, lowest terms would be nice to the graders.

Quick terminology review

IMA/Ideal Mechanical Advantage: ratio of distance out to distance in.
AMA/Actual Mechanical Advantage: ratio of force in to force out.
Efficiency: AMA/IMA, i.e., fraction of work not lost to friction.
Work: $W=F*\Delta x$, i.e., force exerted along a distance (the component of distance parallel to force).
Torque: $\tau = r * F_{perpendicular}$, or the force exerted at a distance (as leverage).
Statics: All net forces and all net torques are 0 everywhere (a net nonzero force causes motion).

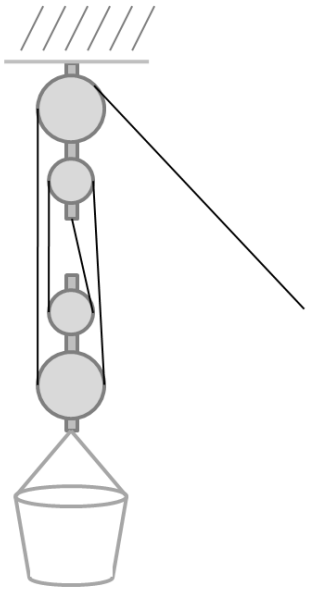
Problem 1 [5 pts]. List the 5 simple machines allowed for the Division B.

Problem 2 [5 pts]. Bus wheel/Car Wheel

Suppose your car steering wheel is a bit hard to turn, so you decide to tape on a bus steering wheel on top of it to steer with. Say your car's steering wheel has radius $r_c = 18\ cm$ and the bus steering wheel has radius $r_b = 22\ cm$. How much more do you need to move your hands on the bus steering wheel than the car steering wheel (in order to turn the same angle)? Answer as a ratio of the distances. Feel free to write a fraction or decimal.

Problem 3 [5+5+5 pts]. Simple Pulley (aka Double Tackle)

Here's a relatively simple pulley system that may be found in a sailboat. (although in a boat they'd probably have something other than a bucket as the load)

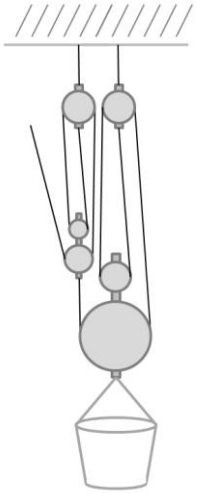


i. Find the IMA of this system.

ii. Suppose Clumsy Joe spilled tar on the pulley system, and now each individual pulley has an efficiency of 80%. What's the AMA of the overall system?

iii. What's the IMA of the system if we flipped it up-side down, so that the load is where the ceiling currently is, and the bucket is fixed in place?

Problem 4 [5+5 pts]. Pulley system

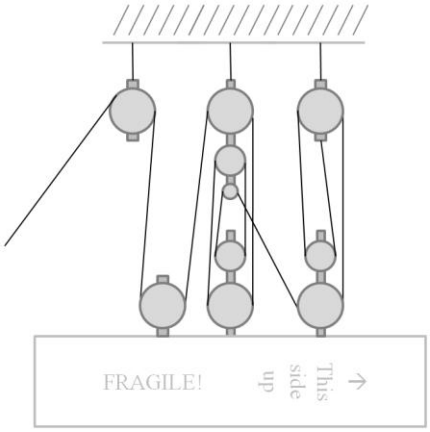


i. What's the IMA of this system?

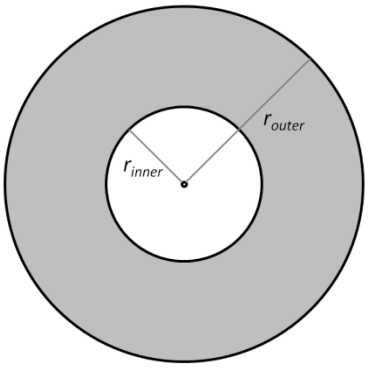
ii. If the rope can withstand a maximum of 10 N, what's the heaviest load that can be lifted before the rope breaks? (answer in Newtons)

Problem 5 [5 pts]. Another Pulley System

Find the IMA of the following system used to lift a mysterious box.



Problem 6 [2.5 x 4 = 10 pts]. Vinyl Record



A vinyl record player turns the record at a constant 33 1/3 rpm. Its outer radius is r_{outer} = *6 inches*, and the inner radius where the grooves end is at r_{inner} = *2 inches*. Suppose grooves are *0.005 inches* apart.

i. How much music can you fit on each side of this record?

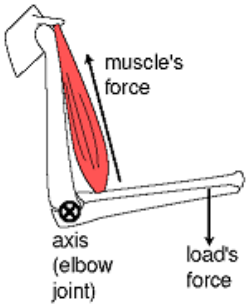
ii. What is the length of groove that corresponds to one second on the outside of the record? (in.)

iii. What is the length of groove that corresponds to one second on the inside of the record? (in.)

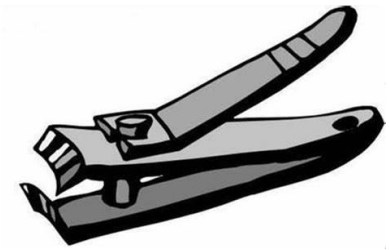
iv. If you want your song to be the highest quality, should you put it at the beginning or end of the track? (fellow kids - the needle starts on the outside and goes inward)

Problem 7 [2 x 5 = 10 pts]. Identify the lever's class

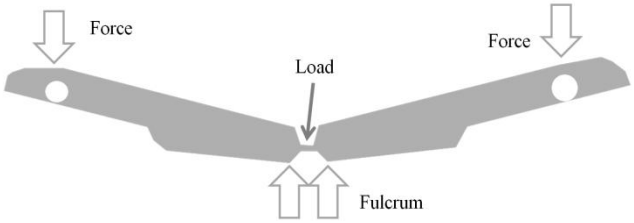
i. Human Arm



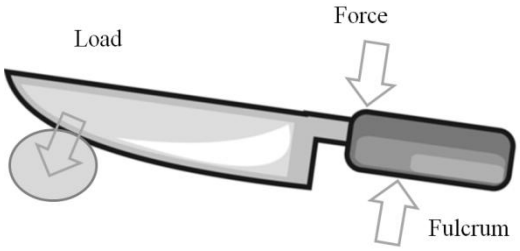
ii. Nail clipper (2 types)



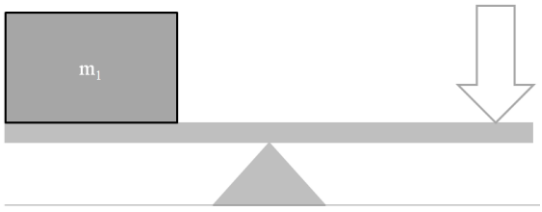
iii. Butterfly key switch (present in some Apple keyboards) -- the load is a piece of plastic that bends and provides a restoring force.



iv. Knife

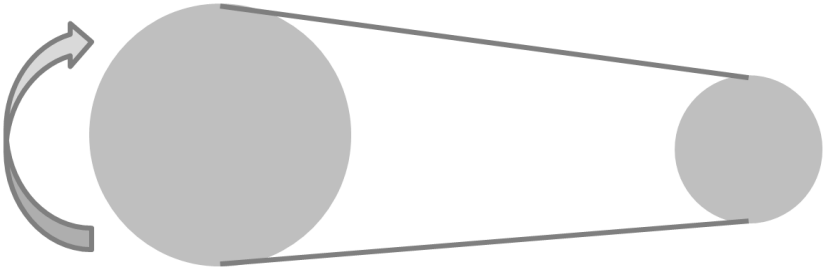


v. See-saw



Problem 8 [5 pts]. Bike chain

Consider the system below. Suppose I drive the left gear, which has a radius of 10 cm. A chain in turn drives the right gear, which has radius 5 cm. What's the IMA of the system? That is, for each centimeter the right gear moves (5 cm out), how many centimeters does the left gear need to move (10 cm out)? (Answer as a unitless ratio)



Problem 9 [5 pts]. High ground

Person A wants to get to the same altitude as Person O. Person O walked up the ramp. If Person A climbs straight up a ladder of height of h instead, how does his average force output (power) compare to Person O's average force output (power) in walking up the ramp? Answer as a ratio: F_A/F_O in terms of h and L. (Hint: who requires more force per time to get to the high ground? You can use this to check if the ratio F_A/F_O should be less than or greater than 1)