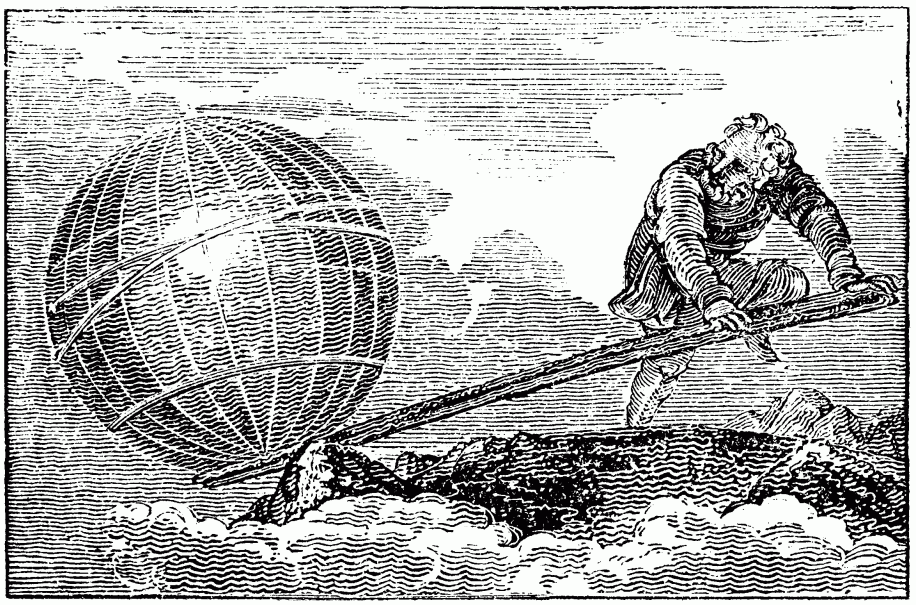
Science Olympiad
Machines C
Golden Gate Invitational

February 13, 2021



Directions:

- Each team will be given **50 minutes** to complete the test.
- There are two sections: **Section A** (Multiple Choice) and **Section B** (Free Response).
- Do not worry about significant figures. Just make sure to **use 3 or more in your answers**.
- Whenever needed, take the acceleration of gravity, g, to be $9.81\,\mathrm{m\,s^{-2}}$
- Tiebreakers, in order: §B, §B2, §B3, §A26, . . . , §A35.
- Best of luck! And may the odds be ever in your favor.

Written by:
Pranit Mohnot, *pranit_mohnot@berkeley.edu*
Robert Lee, *robertyl@ucla.edu*
Sean Lin, *slin092000@berkeley.edu*

Feedback? **Test Code**: *2021GGSO-MachinesC-Cable*

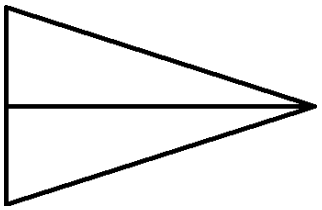
Section A: Multiple Choice

This section is comprised of three subsections, for a total of 70 points.

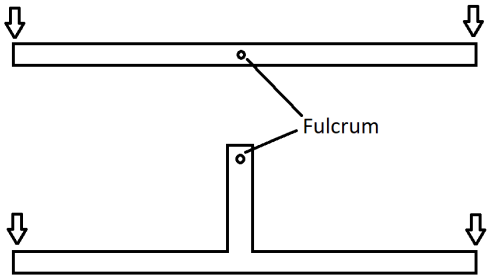
A-I: True/False

There are 10 true/false questions in this subsection, each worth 1 point, for a total of 10 points.

1. The efficiency of an ideal machine is always 1.
2. It is possible for a compound machine to have an AMA greater than any of its individual simple components.
3. It is possible for a compound machine to have an efficiency greater than any of its individual simple components.
4. Keeping all other dimensions constant, it is impossible to preserve the pitch of a screw while changing the thread angle.
5. If two identical inclined planes of IMA x are conjoined as such to create a wedge, the IMA of the wedge is x/2.



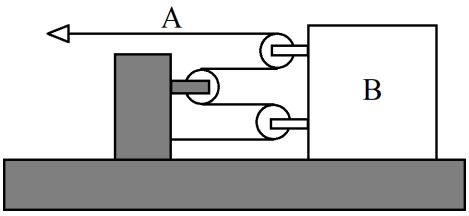
6. It is possible to design a compound system of gears that increases both the rotational speed and torque of an input.
7. The addition of a pulley to the end of an existing pulley system cannot possibly increase the IMA of the system by more than a factor of 2.
8. A brick breaks if impacted by a strike of 100 J. If a hammer with MA = 4 is swung at the brick with 25 J, the brick breaks.
9. Any machine with a mechanical advantage less than 1 serves no practical purpose.
10. The following two levers are functionally identical to each other. (Consider all beams to be massless.)



A-II: Multiple Choice

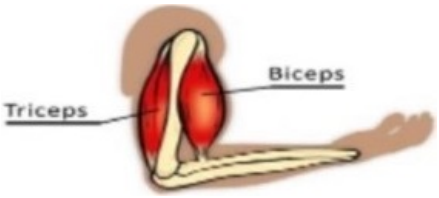
There are 15 questions in this subsection, each worth 2 points, for a total of 30 points.

11. If end A is pulled a distance of 1 m, what distance does block B travel?



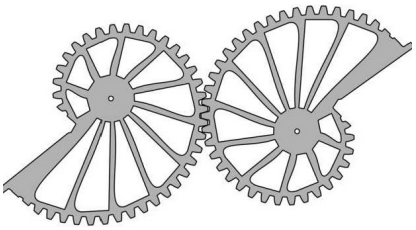
A. 2 m
B. 1 m
C. 1/2 m
D. 1/4 m
E. 1/8 m None of the above

12. Given the following diagram of an arm, what class lever is the forearm when contracting the bicep and tricep respectively? *(Hint: The elbow is the fulcrum.)*



A. I / II
B. I / III
C. II / I
D. II / III
E. III / I
F. III / II

13. What is the name of the following gear system?



A. Hypoid Gears
B. Galactic Gears
C. Spiral Bevel Gears
D. Helical Gears
E. Nautilus Gears
F. Shell Gears

14. What is the minor diameter of a screw with a major diameter of 10 mm, pitch of 1 mm, and thread angle of 50 degree?

A. 9.58 mm
B. 9.16 mm
C. 8.93 mm
D. 7.86 mm
E. 5.71 mm
F. None of the above

15. A hypothetical circular helical ramp with 16 loops has an inner radius of 5 m and is 2 m wide. The total height of the ramp is 32 m. A person in a wheelchair weighs a total of 150 kg and has to be pushed up the ramp with a constant force of 150 N. What is the absolute difference in efficiency between taking a route along the inner edge of the ramp versus the outer edge?

A. 0.89 %
B. 2.23 %
C. 8.92 %
D. 17.84 %
E. 20 %
F. Such a ramp is impossible as its efficiency is over 100 %!

16. You are given the pulley system below. How many pounds should you exert in order to lift the load?

A. 6 lbf
B. 15 lbf
C. 20 lbf
D. 25 lbf
E. 60 lbf
F. 180 lbf

17. Jennifer is an engineering student at UC Berkeley (Go Bears!) and has built her own model crane. She would like to use it to lift a toolbox. Her crane uses a block-and-tackle (with 8 supporting rope segments) to lift objects, a winder with a diameter of 10.0 cm (to pull the rope), fixed axially to a 100-tooth gear. This gear is driven by a 10-tooth gear, which is attached to a motor whose maximum torque is 100 mN·m. What is the heaviest toolbox she can lift, in Newtons? Assume ideal conditions.

A. 40 N
B. 80 N
C. 120 N
D. 160 N
E. 240 N
F. 320 N

18. Now, her friend, John, has built a similar crane, except his crane's block and tackle has 16 supporting rope segments. Also, unlike Jennifer's, his crane is not ideal, and instead has an efficiency of 75 %. He has a bear sculpture that his crane can just barely lift, and he challenges Jennifer to lift it using her crane. Jennifer decides that her crane could not lift this box on its own, and decides to use an ideal inclined plane. What is the largest angle this inclined plane can make with the ground for the crane to lift the sculpture? Answers are to the nearest degree.

A. She doesn't need an inclined plane; her crane can lift the box as is!
B. An inclined plane would not be able help her, no matter what!
C. 27°
D. 38°
E. 42°
F. 63°

19. A seesaw is balanced when Henri sits 6 feet from the pivot, and Alex sits 5 feet from the pivot on the other side. Unfortunately, it is exam season, and they have different coping mechanisms for finals stress. Henri eats an entire pizza every night, whereas Alex begins to exercise more. If Henri weighed 130 pounds before exam season, and gained 15 pounds by the end, and the two can now balance a seesaw by sitting the same distance from the pivot, how much weight did Alex lose?

A. He lost 5 pounds
B. He lost 11 pounds
C. He lost 13 pounds
D. He lost 15 pounds
E. He actually gained 5 pounds, somehow
F. He actually gained 15 pounds, somehow

20. A person tries to swat a fly, with a fly swatter that is 1 foot long. The person's forearm is 18 inches long, and for this problem we will assume that the person's biceps exert a maximum force of 15 lbf at the middle of the forearm (assume that this force is applied at an angle of 30° from the forearm). The fly somehow survives! What force did the fly have to exert on the swatter to prevent it from being squashed? *(Note: Assume that the fly swatter/person are massless.)*

    A. 0.750 lbf

    B. 1.50 lbf

    C. 2.25 lbf

    D. 3.90 lbf

    E. 12.5 lbf

    F. 43.3 lbf

21. A block starts with zero velocity at the top of a ramp that is 2 meters tall and 1 meter horizontally, and has an efficiency of 80 % Then, it slides along a frictionless surface, until it reaches a frictionless curve, whose height increases with the square of the distance. What is the highest vertical distance the block reaches on the parabolic curve?

    A. This question is impossible to answer without the use of calculus.

    B. 1.00 m

    C. 1.28 m

    D. 1.33 m

    E. 1.6 m

    F. 2 m

22. A first class lever acts as a catapult. The "ammunition" is at a distance of 1 meter to the left of the fulcrum. The effort force is applied at a distance of 3 meters to the right of the fulcrum. The ammunition launches vertically, and reaches a height of 20.4 meters. What was the velocity of the point where the effort was applied at the instant that the ammunition lost contact with the catapult?

    A. $6.67\,\mathrm{m\,s^{-1}}$

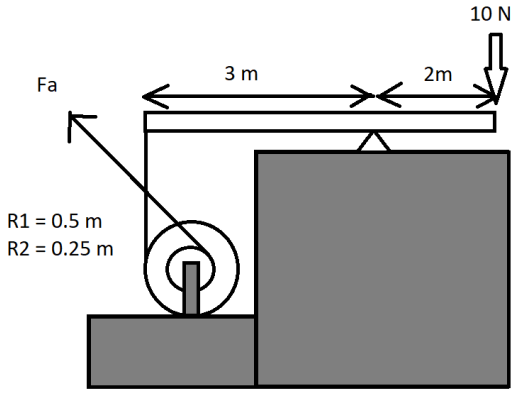
    B. $20.0\,\mathrm{m\,s^{-1}}$

    C. $42.4\,\mathrm{m\,s^{-1}}$

    D. $56.5\,\mathrm{m\,s^{-1}}$

    E. $60.0\,\mathrm{m\,s^{-1}}$

Questions 23 and 24 refer to the following diagram.



23. Assuming the compound machine is ideal and at rest, what is the value of F_A?

    A. 20 N

    B. 30 N

    C. 40 N

    D. 50 N

    E. 60 N

24. Now, assume the wheel and the lever beam both have small, and uniform mass. A new force F_B is now required to sustain the load. What is the relationship between $|F_A|$ and $|F_B|$?

    A. $|F_B| < |F_A|$

    B. $|F_B| > |F_A|$

    C. $|F_B| = |F_A|$

    D. A combination of two of A, B, and C.

    E. The relationship is indeterminate.

25. There are five non-reversible (the input and output **cannot** be switched) simple machines with IMAs of 2, 3, 3, 9, and 14. How many possible unique IMA values can be made through the combinations of these five machines? Assume that using none of the machines results in an IMA of 1.

    A. 1 to 5

    B. 6 to 10

    C. 11 to 15

    D. 16 to 20

    E. ≥ 21

A-III: Multiple Select

There are 10 questions in this subsection, each worth 3 points, for a total of 30 points.

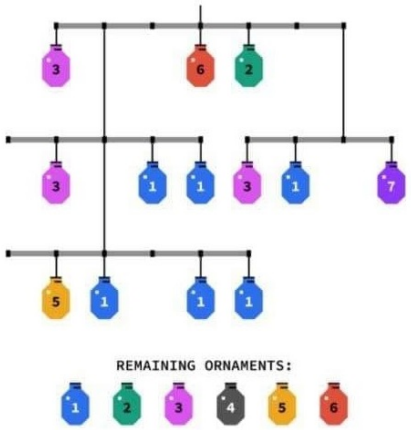
26. A contractor provides the following:

    1. A lever with AMA = 10, IMA = 20
    2. A pulley with AMA = 3, IMA = 4
    3. An inclined plane w/ AMA = 2, IMA = 6

    The contractor hires you to create machines with the following requested efficiencies. Select all requests that are impossible.

    A. 37.5 %
    B. 33.3 %
    C. 25 %
    D. 20 %
    E. 14.3 %
    F. 12.5 %

27. The following mobile is currently balanced and contains multiple open attachment points. Six ornaments remain with weights 1, 2, 3, 4, 5, and 6. There is a maximum number of remaining ornaments that you can place on the mobile and keep it in balance. Select all ornaments in this maximal set (question courtesy of Brilliant).



    A. 1
    B. 2
    C. 3
    D. 4
    E. 5
    F. 6

28. You must design a contraption with a load force of at least 117 Newtons over a distance of at least 12.3 cm. Unfortunately, the maximum effort force you can exert is only 34.1 Newtons, and you are limited to a maximum effort distance of 85.9 cm. Assuming a perfect efficiency, which of the following are acceptable mechanical advantages for your machine? Select all that apply.

    A. 3.02
    B. 4.91
    C. 5.67
    D. 6.64
    E. 7.25
    F. None of the above

29. Use the same problem statement as the previous problem, but assume an efficiency of 53 %.

    A. 3.02
    B. 4.91
    C. 5.67
    D. 6.64
    E. 7.25
    F. None of the above

30. Which of the following are examples of third-class levers? Select all that apply.

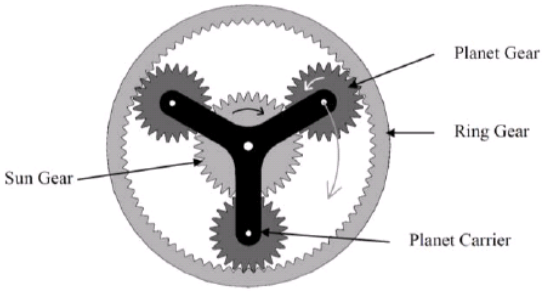
    A. Tongs
    B. The blade of an axe cutting through wood
    C. Scissors
    D. An axe being swung
    E. Screwdriver
    F. A tennis racquet being swung

31. Which of the following are examples of wheels-and-axles? Select all that apply.
    A. Circular Faucet Tap
    B. Screwdriver
    C. Bicycle gear
    D. Nails
    E. Spiral Staircase
    F. Drill bits

32. Which of the following are examples of the screw simple machine? Select all that apply.
    A. Circular Faucet Tap
    B. Screwdriver
    C. Bicycle gear
    D. Nails
    E. Spiral Staircase
    F. Drill bits

33. Your friend boasts that he has created the first real-life ideal compound machine. Being a good scientist, you are very skeptical, so of course, you inspect the device by using it yourself to lift a heavy load. Eventually, you become exhausted, but only after finding that it makes squeaky noises, that both the joints and the handle are slightly warmer after you use it (it was room temperature before, and the device is made of a good thermal insulator), and that you have to move your arms much faster than the load ends up moving. Select all the reasons why you know the device can not be ideal.
    A. The device *can* be ideal.
    B. You get tired.
    C. The joints are warmer after being used.
    D. The handle is warmer after being used.
    E. You must move your arms much faster than the load moves.
    F. The device is squeaky.

34. The pictured gear system is called a planetary gear. Traditionally, the input is the largest outer gear and the output is an axle attached to the central sun gear. Select all practical applications of planetary gears.



    A. Torque reduction
    B. Torque magnification
    C. Speed reduction
    D. Speed magnification
    E. Compactness/spatial efficiency
    F. Vehicle transmission

35. You are using a simple class 1 lever to weigh two objects, where both objects are placed 50 cm from the fulcrum. However, the scale is inaccurate due to a friction torque at the fulcrum modeled by the equation $\tau_f = 0.2(m_1 + m_2)$ (in standard SI units) where m_1 and m_2 are the two masses on the lever. Select all of the following masses that result in a "balanced" scale.
    A. 0.01 kg and 0.01 kg
    B. 250 lb and 215 lb
    C. 0.64 lb and 318 g
    D. 2100 kg and 2250 kg
    E. 48 g and 52 g
    F. 91 tons and 83 tons

Section B: Free Response

Points are shown for each question or sub-question, for a total of 90 points.

1. (12 points) Definitions! (If the answer to any question is a lever, specify what class of lever.)
   (a) (2 points) Define a simple machine.
   (b) (2 points) Define a compound machine.
   (c) (2 points) How do you find the IMA of a compound machine, given the IMAs of its components?
   (d) (2 points) What is meant by the efficiency of a machine?
   (e) (2 points) Which simple machine is the hull of a ship as it moves through the water?
   (f) (2 points) Which simple machines are used in a wheelbarrow?

2. (30 points) As we cannot conduct the device testing portion of the event, you will draft up a design of a device, which should be able to determine a mass ratio up to 12:1. It **must** consist of **two out of the three** following simple machines: **wheel and axle** (must use two), **wedge** (the angle is adjustable), or **pulley** (can use up to two pulleys, fixed or moveable).
   (a) (2 points) Give a one sentence explanation of your device design.
   (b) (12 points) Draw **two device diagrams**.
      i. Diagram 1:
         1. View is from an angle so it is 3-dimensional.
         2. Major features are labeled (i.e. simple machine types, mass locations, etc.)
      ii. Diagram 2:
         1. View is from the side so it is 2-dimensional.
         2. Important dimensions are labeled (i.e. simple machine dimensions, device base width, etc.)
   (c) (8 points) You are given 3 known masses: mass A = 600 g, mass B = 50 g, and mass C = 60 g. You will place two pairs of masses (A&B and B&C, so **two masses at a time**) on your device such that it is in equilibrium. For each pair of masses:
      1. Draw a simple diagram with the location of the masses indicated.
      2. Work through the appropriate calculations to show the device is balanced.

      You should have **two diagrams** and **two sets of calculations**.
   (d) (8 points) Listed below are three potential sources of error, each corresponding to a simple machine. Separately consider **two sources of error**. Explain how each would affect your device (How does it change your device? How could it increase and/or decrease the mass ratio?) and provide a possible solution to remove or diminish the error.
      1. Wheel and axle: non-uniform (nor radially-uniform) wheel density
      2. Wedge: error in the wedge angle
      3. Pulley: axial friction

3. (12 points) A spring is attached to the bottom of a first class lever at a distance d to the right of the lever's fulcrum. A uniform cube of mass M is placed at a distance of D on the left of the fulcrum, resulting in the spring elongating by $D/10$. The force applied by this spring is given by kx, where k is the spring constant, and x is the displacement of the spring. Assume the lever beam is massless and the fulcrum is frictionless.

   (a) (3 points) In terms of M, g, and d, find the spring constant.

   (b) (2 points) Now, a sphere of mass $3M$ is placed somewhere on the lever. The spring relaxes by $D/30$ (meaning it is still elongated by some amount). Is the new mass placed on the same side as the spring, or the same side as the cube? Explain.

   (c) (4 points) In terms of D, how far from the fulcrum is the sphere?

   (d) (3 points) Now, the sphere is moved to the other side of the fulcrum, but remains at the same distance from the fulcrum. In terms of D, what is the new total elongation of the spring (relative to when the spring has no load on it)?

4. (12 points) A block of mass M is pushed up a frictionless curve, where the angle of inclination slowly increases with horizontal distance.
   For parts (a), and (b), assume that you apply a force F (where $F < Mg$) on the block such that the force is maximally effective in pushing the block up the curve. For parts (c) and (d), assume that you apply a force P that is always horizontal.

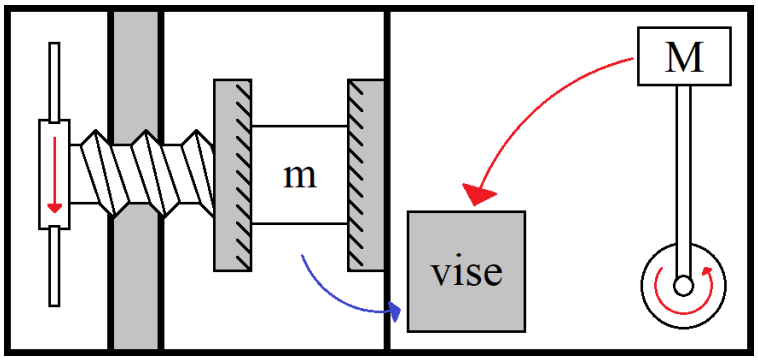
   (a) (1 point) In which direction is the force F exerted on the block?

   (b) (3 points) What is the largest angle of inclination that the block can reach when the force F is applied? Give your answer in terms of M, F, and fundamental constants, as appropriate.

   (c) (4 points) What is the largest angle of inclination that the block can reach when the force P is applied? Give your answer in terms of M, P, and fundamental constants, as appropriate.

   (d) (4 points) How much work will have been done on the block when it can no longer move any further? Give your answer in terms of M, P, and fundamental constants, as appropriate. If impossible to answer, explain why.

5. (24 points) The diagram below depicts a vise system and your friend's proprietary design of her Smash-O-Matic™ (patent pending). Assume all components are frictionless and ideal unless otherwise specified.



(a) (10 points) On the left of the diagram is your vise, consisting of a single-start screw with a 5 cm screw cap diameter and a 5 mm lead. The screw also has two rods, each 30 cm long, welded onto the edge of the screw cap by their ends. A block of mass m ($m = 8$ kg) is placed in the vise and tightened between two identical rough surfaces.

i. (2 points) To use the vise, you apply a force at the end of the rods and a force is exerted by the plate onto the mass m. What is the IMA of the vise?

ii. (2 points) Most vises (and screws) are self-locking. What would be the maximum AMA of your vise if it is self-locking? *(Note: Do not use this AMA for the following sub-questions.)*

iii. (3 points) You apply a force of 10 N on the end of a rod to hold the block still. If it takes a downwards force of 120 N to move the block, calculate the coefficient of static friction between the block and the rough surfaces.

iv. (3 points) What is the minimum upwards force to move the same block, in N?

(b) (14 points) On the right of the diagram is the Smash-O-Matic™, which consists of a hammer, with a 1 kg head and a 40 cm handle, connected to a motor that outputs a constant torque of 3 Nm. The "vise" square represents a side profile of the clamped block. The hammer begins upright and accelerates until it's horizontal. Then, the head is released from the handle and immediately hits the block. The hammer head and block collide perfectly inelastically and travel together, until they come to rest. Assume the handle mass is negligible, the block and hammer head stay in the vise, and the same, constant 10 N force is applied to the vise.

i. (3 points) Find the velocity of the hammer head right before it hits the block, in $\mathrm{m\,s^{-1}}$.

ii. (3 points) Find the velocity of the hammer head right after it hits the block, in $\mathrm{m\,s^{-1}}$.

iii. (3 points) Determine the energy efficiency of the collision, in %.

iv. (5 points) Given the coefficient of kinetic friction is 0.015, how far does the block travel before it comes to rest, in cm?