



Exploring the World of Science

University of Michigan Science Olympiad 2021 Invitational Tournament

Machines C

Test length: 50 Minutes

Team name: KEY

Student names: KEY

Use $g = 9.81 \text{ m/s}^2$.

The Tiebreakers for this test will be: 35, 14, 23

Write numerical answers as decimal numbers to 2 decimal places unless told otherwise.

Part 1: Multiple Choice/Fill in the blank/True-false (2 points per question)

1. An inclined plane makes an angle θ with the horizontal. The AMA of the system is x . What is the efficiency of this simple machine?

- A. $x \cos \theta$
- B. $x \sin \theta$
- C. $\frac{x}{\cos \theta}$
- D. $\frac{x}{\sin \theta}$
- E. $x \tan \theta$

2. A wedge in the shape of an isosceles triangle has a base angle of 17° . What is its IMA?

- A. 3.27
- B. 1.64
- C. 3.35
- D. 6.77

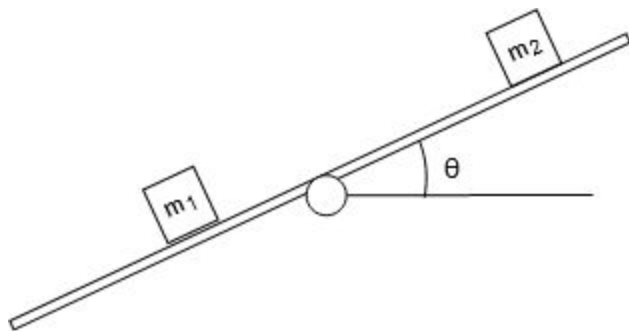
3. A wedge in the shape of a right triangle has a tip angle of 22° . What is its IMA?

- A. 2.48
- B. 1.24
- C. 2.57
- D. 2.67

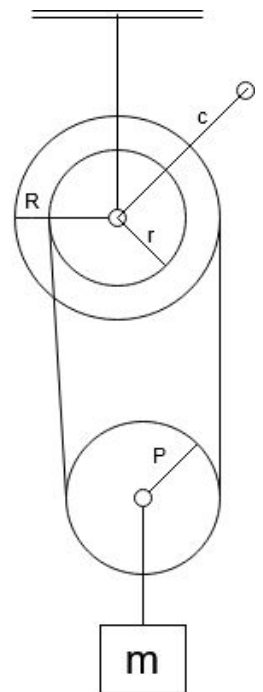
4. The diagram to the right shows a windlass with a crank length of $c=20$ cm, drum radii of $R=10$ cm, $r = 9$ cm, and a movable pulley radius of $P=8$ cm. If the load mass is $m=3$ kg, what force must be applied to the crank to move the mass up at a constant speed?

- A. .736 N
- B. 13.244 N
- C. 2.943 N
- D. 1.4715 N

5. On the lever below, masses $m_1 = 4$ kg and $m_2 = 3$ kg are 2.4 m and 4.2 m respectively from the fulcrum. The lever is held such that the beam makes an angle $\theta = 42^\circ$ with the horizontal. When the lever is released, how long does it take for the lever to be completely horizontal?

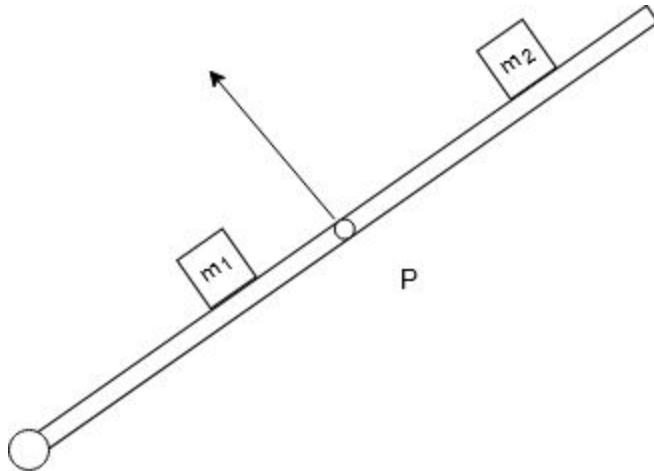


- A. 14.72 s



- B. 2.38 s
- C. 2.26 s
- D. 17.08 s

6. The lever from the previous problem is modified such that the fulcrum is now at the end of the beam. What force must be applied perpendicular to the beam at point P, the previous location of the fulcrum, in order for the lever to remain in equilibrium? P is 5 m from the new fulcrum of the lever, and the lever makes a 45° angle with the horizontal.



- A. 5.37 N
- B. 52.72 N
- C. 74.56 N
- D. 30.80 N

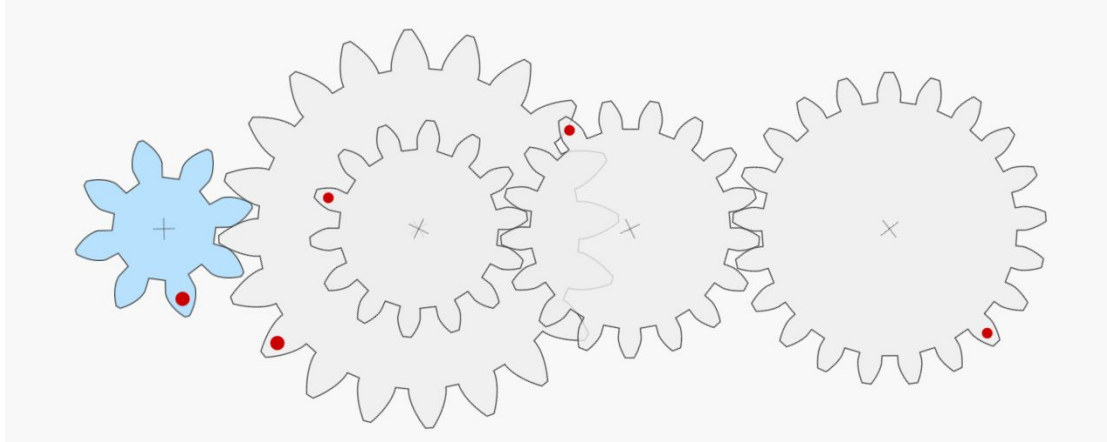
7. A screwdriver with a handle diameter of 3 cm is used to turn a screw with a diameter of 7 mm and a lead of 2 mm. What is the IMA of this system?

- A. 26.93
- B. 47.12
- C. 32.99
- D. 21.99

8. A block is at rest 5 meters along the slope from the bottom of an inclined plane at an angle of 23° with the horizontal. The block then slides down the plane. When the block slides off the inclined plane, it is traveling at 3.14 m/s. What is the coefficient of friction of the ramp?

- A. .315
- B. .977
- C. 2.10
- D. .121

9. The following gear train has gears with 8, 20, 14, 17, and 21 teeth from left to right, back to front. What is the gear ratio between the first and last gears?



- A. $\frac{15}{4}$
- B. $\frac{21}{8}$
- C. $\frac{15}{2}$
- D. $\frac{105}{34}$

10. Two gears are meshed such that the output gear is rotating at 40 rpm clockwise. A gear with twice the amount of teeth as the input gear is inserted between the input and output gear. What is the (clockwise) rotation of the output gear now?

- A. 40 rpm
- B. -20 rpm
- C. 80 rpm
- D. -40 rpm

11. What is the gear inserted in question 10 called? _____

12. A wheel and axle system is spinning. Which part of the system will slow the wheel down faster if it comes into contact with a surface with friction with equivalent coefficients?

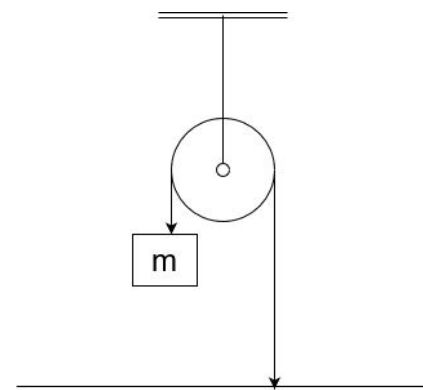
- A. the wheel
- B. the axle

13. A block and tackle system is rove to advantage. A block and tackle system with the same IMA that is rove to disadvantage would require _____ pulleys

- A. more
- B. less
- C. the same number of

14. A pulley is suspended from the system as shown in the diagram on the right, such that the right rope is attached to the floor. What force does the pulley system exert on the ceiling, if m is the mass of the block?

- A. mg
- B. $\frac{mg}{2}$
- C. $2mg$
- D. $\frac{mg}{3}$
- E. $3mg$



15. Screw A has a thread angle of 22° and Screw B has a thread angle of 29° . Which has a higher IMA?
- Screw A
 - Screw B
 - Equal
 - Not enough information
16. Which of these types of gears can transfer motion between non-parallel shafts at any given angle?
- spur
 - pinion
 - bevel
 - miter
17. Which of these qualities are preserved between two ideal meshed gears?
- Torque
 - Rotational velocity
 - Linear velocity
 - Direction of rotation
18. True/False: Putting a simple machine in series with another simple machine can increase the overall efficiency of the system.
19. A block is at rest on an inclined plane of angle θ . Which of the following must be true?
- $\mu_s \leq \tan \theta$
 - $AMA > 1$
 - $AMA < 1$
 - $\mu_s \geq \tan \theta$
20. You push two blocks A and B each with an identical force for the same amount of time up an inclined plane with a static coefficient of friction $\mu = \tan \theta$, where θ is the angle of the inclined plane. If the mass of block A is greater than the mass of block B, which block comes to rest higher up the inclined plane?
- A
 - B
 - They stop at the same height

Short Answer Questions:

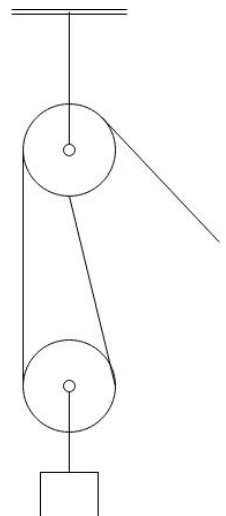
21. What is the name of the pulley system to the right?

block and tackle (2 points)

22. If the pulleys in this system start to rotate when an effort is applied, what does that imply about the tension in the rope on each side of the pulleys?

the tensions are not equal, since there is a net torque on the pulley (2 pts)

23. A gear system has an equal number of teeth in the input and output gears, so that the gear ratio is 1:1. Why might 1 gear be inserted in between the input and output? Why might 2?

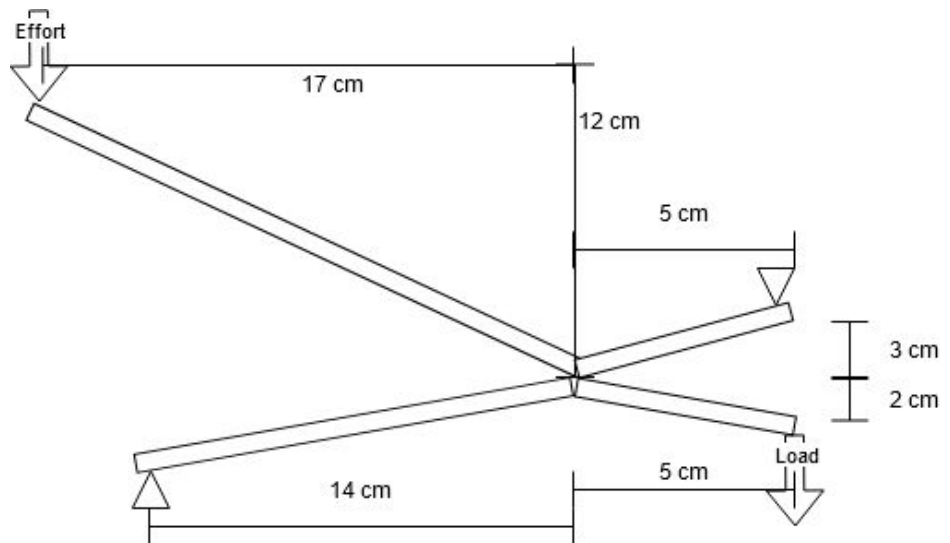


For 1, any of the following: to reverse direction of rotation, to transfer motion using smaller gears, to prevent wear by using coprime gear number of gear teeth (2 points)

For 2, any of the following: to transfer motion using smaller gears, to prevent wear by using coprime gear number of gear teeth (2 points)

Free Response Questions - write numerical answers as decimal numbers to 2 decimal places unless told otherwise.

The following diagram is a model of the levers at work inside a nail clipper. The effort and load forces are all applied vertically.



24. The top lever is a class 2 lever, and the bottom lever is a class 3 lever. (1 pt each)

25. What is the total IMA of this system? 3.24

26. Show your work/intermediate steps for the previous question here for potential partial credit

IMA = IMA1*IMA2 - 1 point

Getting correct IMA for top or bottom lever (22/5 or 14/19) - 1 point

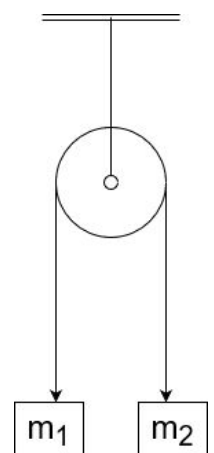
27. The system to the right is often used to study systems in constant acceleration.

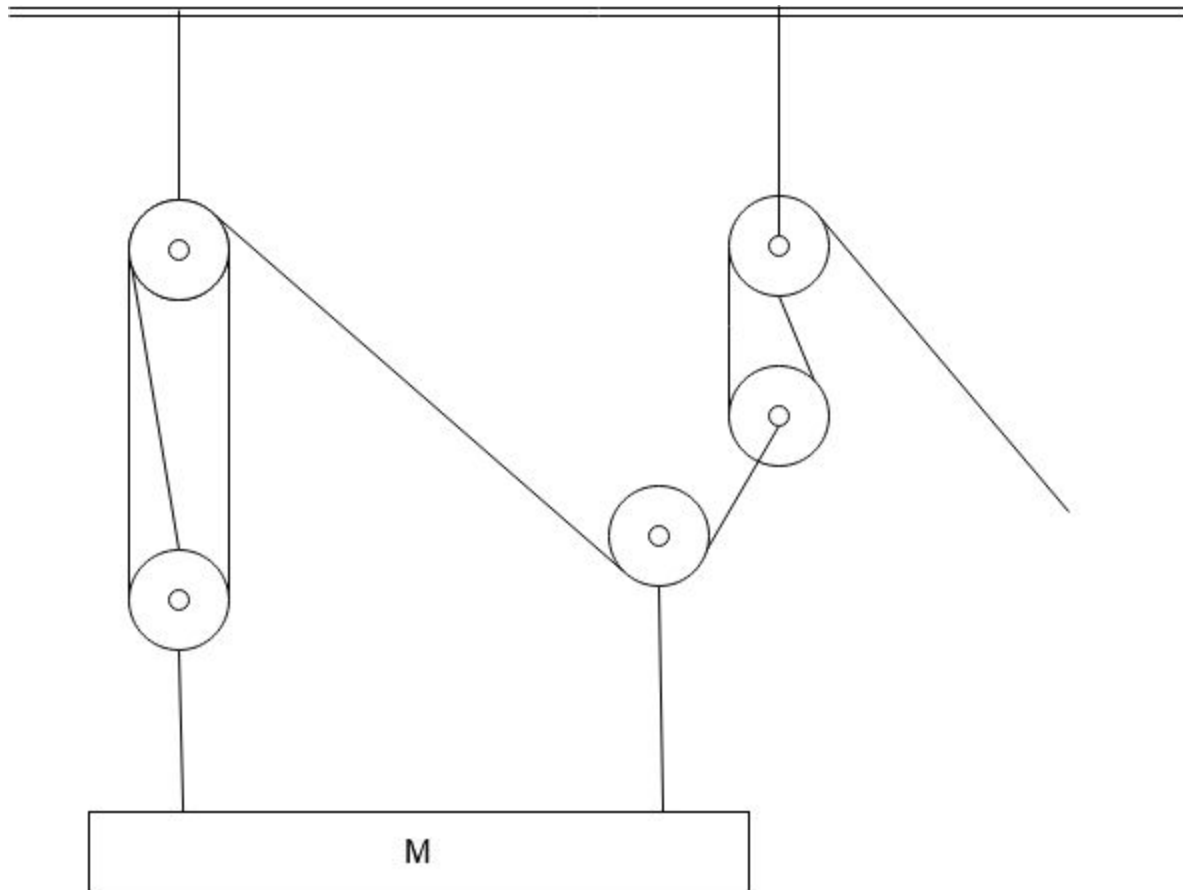
What is it called? Atwood machine (1 pt)

28. Using g as acceleration due to gravity, and m_1 , m_2 as the masses of the blocks, derive the acceleration of block m_1 .

$$a = g \frac{m_1 - m_2}{m_1 + m_2}$$

Partial Credit - using $F=ma$ on the blocks including tension - 2 points





29. What is the IMA of the pulley system? **10 (3 pts)**

30. A mass of 5 kg is attached to the right end of the rope to act as an effort. Given that the load mass M has a mass of 35 kg and that the effort mass moves downward by 4.995 meters in 3 seconds, what is the efficiency of this system? **.79 (4 pts)**

31. Show your work/intermediate steps for the previous question here for potential partial credit

Finding acceleration of the block - 1 point

efficiency = AMA/IMA - 1 point

Finding Fin and Fout to find AMA - 1 point

32. You apply a force to the end of a screwed-in screw to try and push it backwards. No matter how hard you push, the screw stays still. What is the maximum efficiency of this screw?

.50 (2 pts)

33. The screw has a helix angle of 27° and a mean thread radius of 5 mm. What is the IMA of this screw when screwed in by a screwdriver with radius 4 cm?

4.08 (4 pts)

34. Show your work/intermediate steps for the previous question here for potential partial credit

$\tan \theta = \frac{2\pi r}{P}$ - 1 point, $IMA = \frac{2\pi L}{P}$ - 1 point

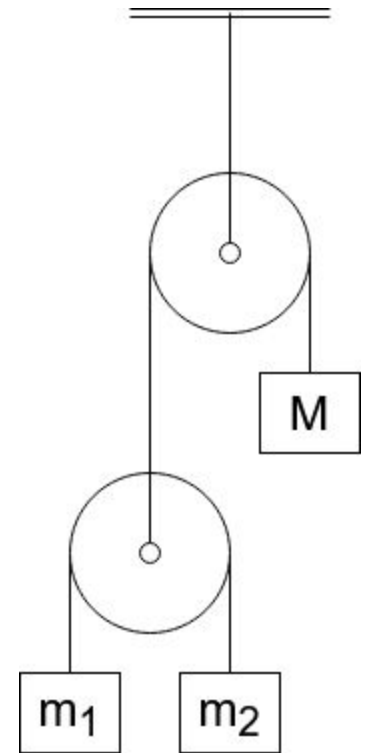
35. Three masses and two pulleys are arranged as in the diagram on the right. m_1 and m_2 are fixed at 15 and 3 kg respectively. If $M = 10$ kg, what is the acceleration of all three blocks in $\frac{m}{s^2}$, taking up to be positive?

m_1 : -6.54, m_2 : 6.54, M : 0 (2 pts per)

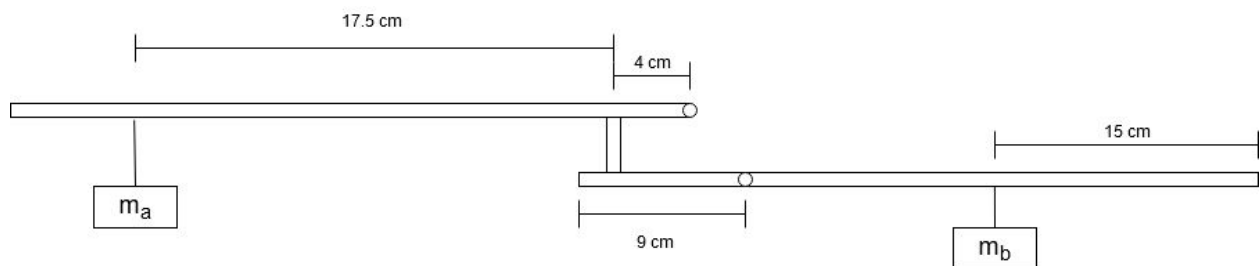
finding tension in left string - 1 point (if 1st two were wrong)

realizing that left pulley exerts 2T on the right pulley - 2 points

36. Show your work/intermediate steps for the previous question here for potential partial credit.



37. A system of levers is made with 40 cm long beams, with the circles representing the fulcras.



37. The system is currently in equilibrium. What is the ratio $\frac{m_a}{m_b}$, assuming ideal conditions?

.33 (3 pts)

IMAs of each lever - 1 pt

38. The beams are 1 cm tall and .5 cm wide and made of wood with a density of .78 g/cm³. Now, in the same scenario as A., but not disregarding the mass of the beams, if $m_a = 300.0$ g, what is the new ratio between masses A and B?

.32

39. If $m_a = 20.0$ g, what is the mass ratio now?

.11

Finding the mass of the wood beams - 1 point

Having the wood beams act at their center of mass - 2 points

Summing up the torques on the second beam to find m_b - 2 points

40. Show your work/intermediate steps for the previous three questions here for potential partial credit