Standard 4.1

Energy Definitions & Calculations — Hard Practice Set

Standard 4.1 is about identifying the energies in a system and answering both qualitative and quantitative questions on work, power, kinetic and potential energy in a closed system, and pulleys and mechanical advantage. This set opens with concept and definition questions, then drills the calculations behind them. Use $g = 9.8$ m/s^2 everywhere. Show every step. Full worked solutions and the single most common mistake are in the answer key.

MEDIUM HARD DIABOLICAL

Concepts, Definitions & Qualitative Reasoning

MEDIUM

C1. Name the main energy transformation in each case: (a) a diver steps off a high platform and falls to the water; (b) a car brakes to a stop on level road; (c) a compressed spring launches a ball straight up; (d) a pendulum swings from its highest point down to its lowest.

MEDIUM

C2. For each force, state whether it does positive, negative, or zero work, and why: (a) the normal force on a book resting on a table; (b) gravity on a satellite in a circular orbit; (c) friction on a box sliding to a stop; (d) the tension in a rope as you lift a bucket straight up at constant speed.

MEDIUM

C3. Two elevators each do 50,000 J of work lifting identical loads. Elevator A takes 10 s; Elevator B takes 25 s. (a) Which delivers more power, and how much does each deliver? (b) By what factor? (c) Do the two elevators use the same total energy? Explain.

HARD

C4. A student claims a block-and-tackle “reduces the work needed to lift a load.” (a) For an ideal, frictionless system, is that true? (b) What does the machine actually reduce, and at what cost? (c) In a real system, is the work you put in more or less than lifting the load straight up? Explain using conservation of energy.

MEDIUM

C5. Rank the kinetic energies of these four objects from greatest to least: (i) 2 kg at 3 m/s, (ii) 1 kg at 6 m/s, (iii) 4 kg at 2 m/s, (iv) 3 kg at 3 m/s. Show each value.

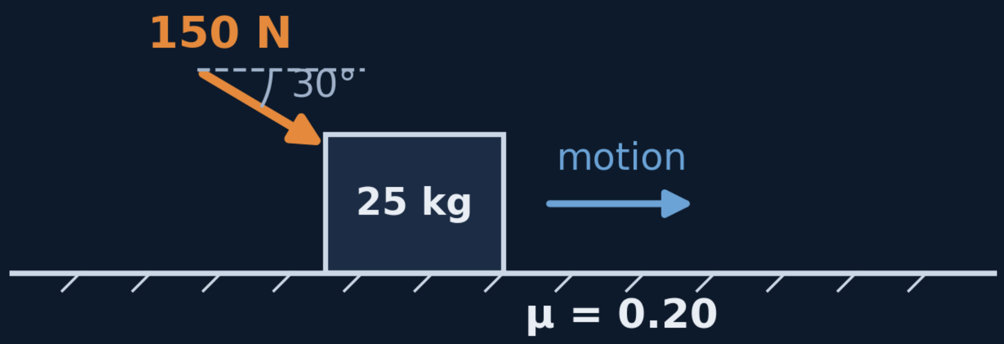
MEDIUM

C6. A 5.0 kg box sits on a shelf 2.0 m above the floor. (a) Find its gravitational potential energy relative to the floor. (b) Find it relative to a 1.0 m table. (c) Does changing the reference level change anything physical about the box? Explain.

Work & the Work–Energy Theorem

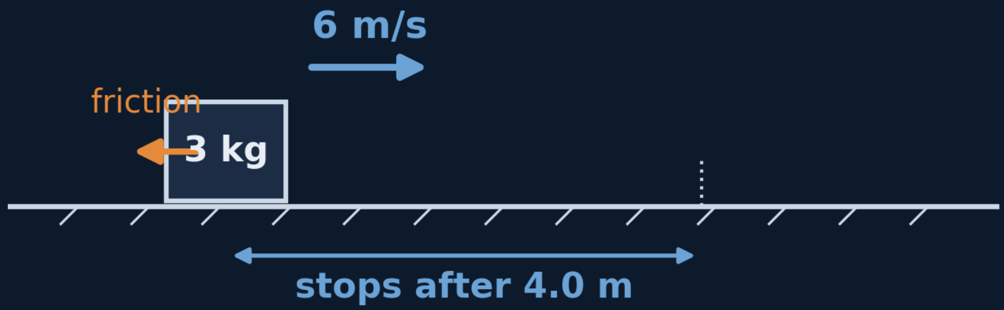
MEDIUM

1. A worker pushes a 25 kg crate 12 m across level ground with a 150 N force aimed 30° below the horizontal. The floor has friction coefficient 0.20. Find (a) the work done by the applied force, (b) the work done by friction, (c) the net work, and (d) the crate's final speed from rest.



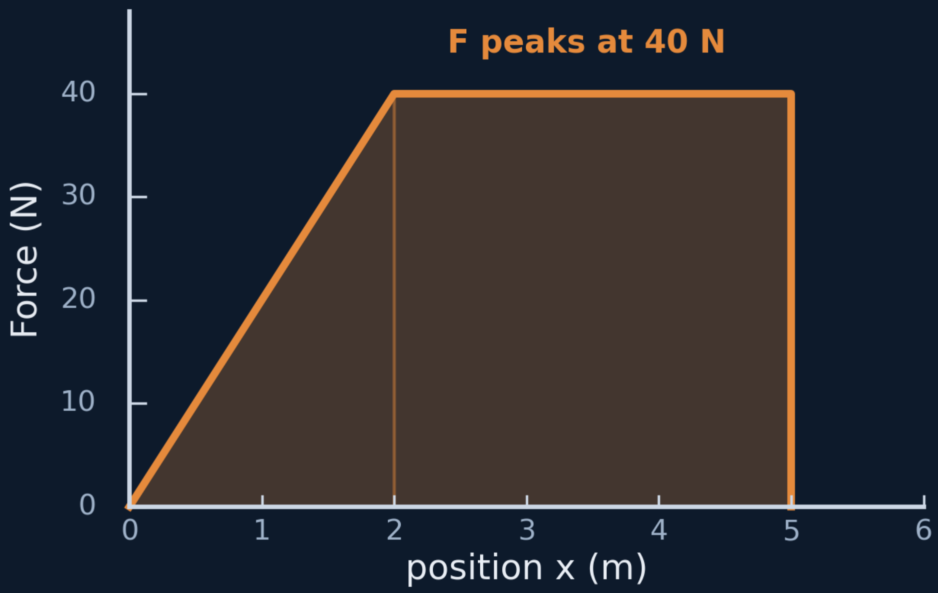
MEDIUM

2. A 3.0 kg block slides across a rough floor at 6.0 m/s and comes to rest after 4.0 m. Using the work–energy theorem, find (a) the work done by friction, (b) the friction force, and (c) the coefficient of kinetic friction.



HARD

3. A machine pushes a 4.0 kg cart along a track with a force that varies with position as shown in the graph. The force rises from 0 to 40 N over the first 2.0 m, then holds at 40 N out to 5.0 m. Find (a) the total work done (the area under the graph) and (b) the cart's final speed if it starts from rest.



Power

MEDIUM

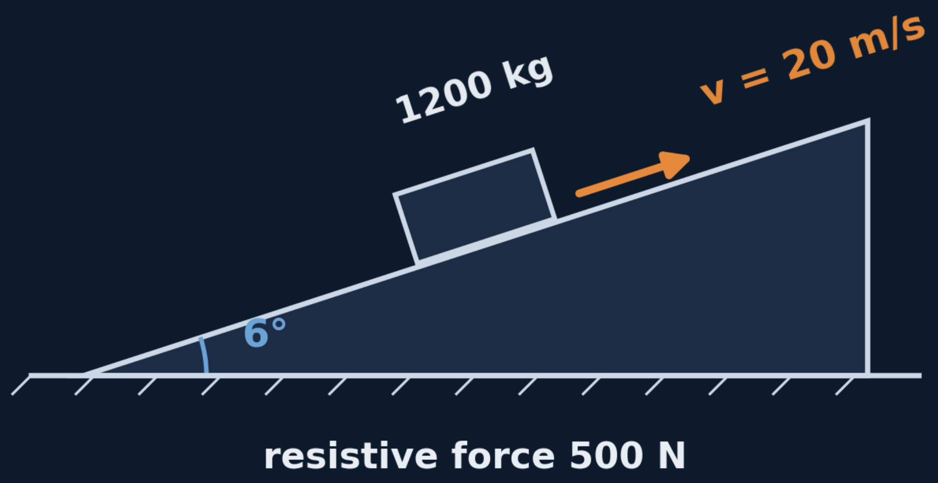
4. A 1500 kg elevator rises at constant velocity through 40 m in 16 s. (a) Find the power the motor delivers. (b) If the motor is 80% efficient, find the electrical power it draws.

MEDIUM

5. A 65 kg student runs up a 4.2 m staircase in 5.0 s. Find the student's power output (a) in watts and (b) in horsepower (1 hp = 746 W).

HARD

6. A 1200 kg car climbs a 6° incline at a constant 20 m/s against a resistive force of 500 N. Find the power output of the engine.



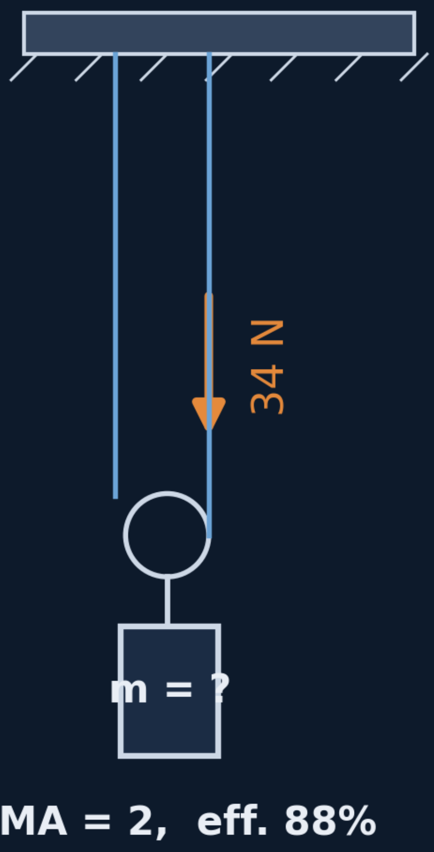
Kinetic & Potential Energy in a Closed System

HARD

7. A 0.145 kg baseball is thrown straight up and rises to a maximum height of 28 m (ignore air resistance). (a) Find its launch speed and initial kinetic energy. (b) At what height is it moving at exactly half its launch speed?

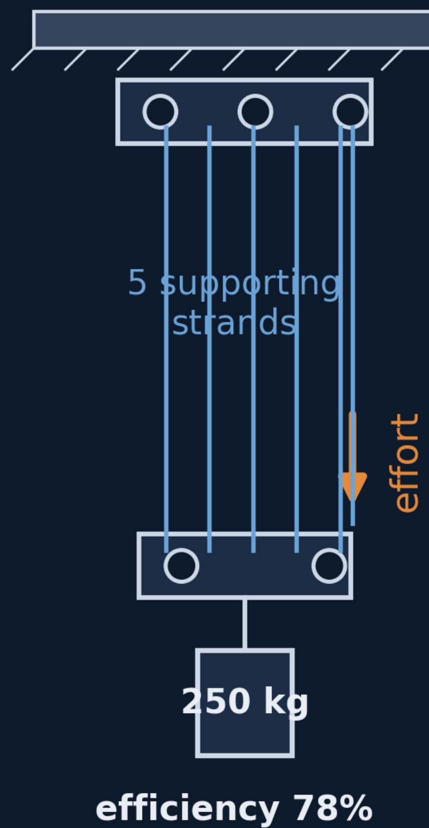
MEDIUM

8. The single movable-pulley system shown (ideal mechanical advantage 2) is 88% efficient. You pull with 34 N to raise the load at constant speed. What mass is being lifted?



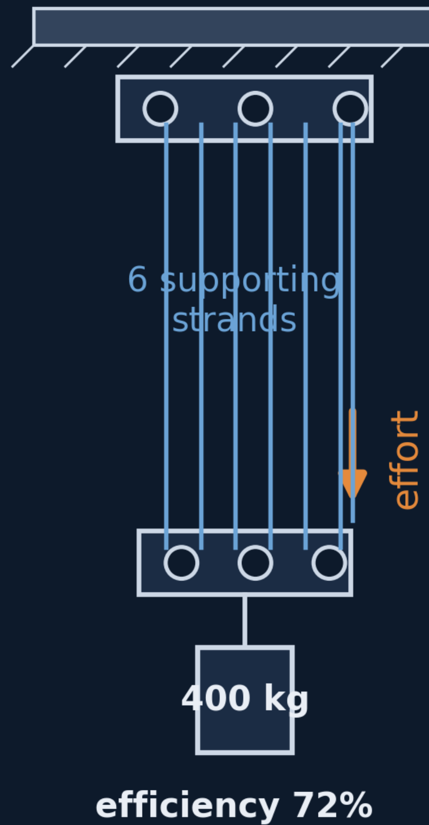
HARD

9. The block-and-tackle shown lifts a 250 kg load with 5 supporting strands at 78% efficiency. Find (a) the ideal mechanical advantage, (b) the ideal effort, (c) the actual effort, and (d) the length of rope pulled and the work you put in to raise the load 3.0 m.



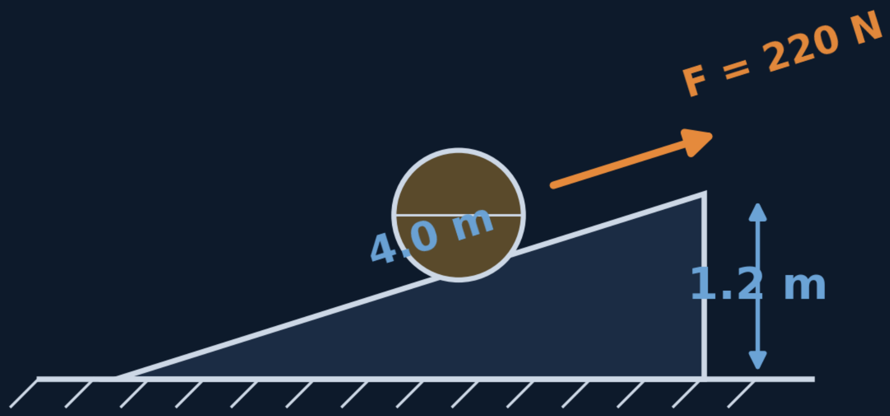
HARD

10. A heavier block-and-tackle lifts a 400 kg load with 6 supporting strands at 72% efficiency. Find (a) the actual effort required, (b) the work input to raise the load 2.0 m, and (c) the energy lost to friction in that lift.



HARD

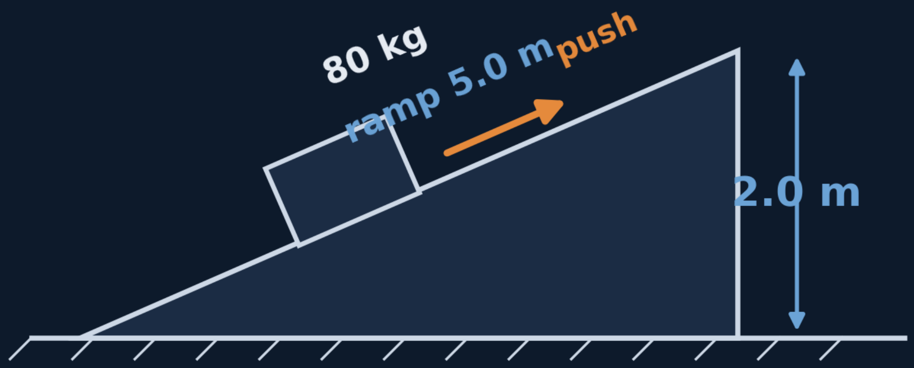
11. A 60 kg barrel is pushed up the 4.0 m ramp shown to a height of 1.2 m. Friction makes the actual force along the ramp 220 N. Find (a) the ideal mechanical advantage, (b) the actual mechanical advantage, (c) the efficiency, and (d) the energy lost to friction over the full ramp.



60 kg barrel

HARD

12. A 80 kg crate is pushed up the 5.0 m ramp shown to a height of 2.0 m. The ramp is 68% efficient and the job takes 8.0 s. Find (a) the ideal mechanical advantage, (b) the ideal effort, (c) the actual effort, (d) the work you put in, and (e) your power output.



68% efficient, job takes 8.0 s

Answer Key — Standard 4.1

C1 — Identifying energy transformations

(a) Gravitational PE → kinetic energy (then to thermal and sound at the splash).

(b) Kinetic energy → thermal energy in the brakes and tires.

(c) Elastic (spring) PE → kinetic energy → gravitational PE at the top.

(d) Gravitational PE → kinetic energy (maximum speed at the lowest point).

Answer: (a) grav PE → KE (b) KE → thermal (c) spring PE → KE → grav PE (d) grav PE → KE

Common error: Saying the energy “disappears” when the car stops. It becomes thermal energy — the brakes heat up.

C2 — When is work positive, negative, or zero?

(a) **Zero** — the book has no displacement (and the force is perpendicular to any horizontal motion).

(b) **Zero** — gravity points to the center while velocity is tangent, so the force is perpendicular to the motion everywhere. That is why orbital speed stays constant.

(c) **Negative** — friction points opposite the motion.

(d) **Positive** — tension acts along the upward displacement.

Answer: (a) zero (b) zero (c) negative (d) positive

Common error: Calling the orbit's gravity positive work. A force perpendicular to the velocity does zero work, no matter how strong.

C3 — Same work, different power

(a) P = W/t. Elevator A: 50,000/10 = **5000 W**; Elevator B: 50,000/25 = **2000 W**. A delivers more power.

(b) 5000/2000 = **2.5×**.

(c) **Yes** — same work means the same energy. Power differs only because A does that work in less time.

Answer: (a) A: 5000 W, B: 2000 W (b) 2.5× (c) yes, same energy

Common error: Thinking more power means more total energy. Power is a rate; the slower elevator uses the same energy spread over more time.

C4 — Does a pulley save work?

(a) **No.** For an ideal machine, work in = work out. Energy is conserved, so the machine cannot reduce the energy required.

(b) It reduces the **force** (the effort), at the cost of making you pull more rope through a greater distance.

(c) **More.** In a real system friction makes work in > work out, so a real machine actually costs a little extra energy. You accept that cost to get the force reduction.

Answer: (a) no (b) reduces force, costs extra distance (c) more work in (friction)

Common error: Believing a pulley "saves work." It trades force for distance and never reduces energy; a real one costs slightly more.

C5 — Ranking kinetic energy

KE = $\frac{1}{2}mv^2$: (i) $\frac{1}{2}\times2\times3^2$ = 9 J; (ii) $\frac{1}{2}\times1\times6^2$ = 18 J; (iii) $\frac{1}{2}\times4\times2^2$ = 8 J; (iv) $\frac{1}{2}\times3\times3^2$ = 13.5 J.

Rank greatest to least: **(ii) 18 J > (iv) 13.5 J > (i) 9 J > (iii) 8 J**.

Answer: (ii) > (iv) > (i) > (iii)

Common error: Ranking by mass or speed alone. KE grows with the square of speed, so the light, fast 1 kg at 6 m/s wins.

C6 — Potential energy and the reference level

(a) PE = mgh = 5.0 × 9.8 × 2.0 = **98 J** relative to the floor.

(b) Relative to the 1.0 m table: 5.0 × 9.8 × 1.0 = **49 J**.

(c) **No.** Only differences in PE are physical. The reference level is a free choice and does not change the box's real state.

Answer: (a) 98 J (b) 49 J (c) no — only PE differences are physical

Common error: Thinking PE has one "true" value. Only changes in PE matter; you are free to pick where zero is.

1 — Work, friction, final speed

W_{app} = F d cos30° = 150 × 12 × 0.8660 = **1558.8 J**.
Push angles down, so N = mg + F sin30° = 245 + 75 = 320 N; f = 0.20 × 320 = 64 N.
W_{fric} = −64 × 12 = **−768 J**. Net = 1558.8 − 768 = **790.8 J**.
$\frac{1}{2}mv^2$ = 790.8 → v = √(2×790.8/25) = **7.95 m/s**.

Answer: (a) 1558.8 J (b) −768 J (c) 790.8 J (d) 7.95 m/s

Common error: Forgetting the downward push raises the normal force, so friction exceeds 0.20 mg.

2 — Work-energy theorem

The block's kinetic energy is destroyed by friction: $KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 3.0 \times 6.0^2 = 54$ J.

(a) $W_{fric} = -KE =$ **−54 J**.

(b) $|W| = f\,d \rightarrow f = 54 / 4.0 =$ **13.5 N**.

(c) $\mu = f / (mg) = 13.5 / (3.0 \times 9.8) =$ **0.459**.

Answer: (a) −54 J (b) 13.5 N (c) 0.459

Common error: Using v instead of v squared in the kinetic energy. KE grows with the square of speed.

3 — Work as area under a force–position graph

Work = area under F vs x. Split into a triangle then a rectangle.

Triangle (0 to 2.0 m, up to 40 N): $\frac{1}{2} \times 2.0 \times 40 = 40$ J.

Rectangle (2.0 to 5.0 m at 40 N): $3.0 \times 40 = 120$ J.

(a) Total W = 40 + 120 = **160 J**.

(b) $\frac{1}{2}mv^2 = 160 \rightarrow v = \sqrt{(2\times160/4.0)} = \sqrt{80} =$ **8.94 m/s**.

Answer: (a) 160 J (b) 8.94 m/s

Common error: Multiplying peak force by total distance (40 × 5 = 200 J). The force is not constant, so you take the area.

4 — Power and efficiency

Useful work = mgh = 1500 × 9.8 × 40 = 588,000 J.

(a) P = W/t = 588,000 / 16 = **36,750 W**.

(b) Input = output / efficiency = 36,750 / 0.80 = **45,937.5 W**.

Answer: (a) 36,750 W (b) 45,937.5 W (≈ 45.9 kW)

Common error: Multiplying by 0.80 instead of dividing. Input power is always larger than output.

5 — Power in watts and horsepower

Work against gravity = mgh = 65 × 9.8 × 4.2 = 2675.4 J.

(a) P = W/t = 2675.4 / 5.0 = **535 W**.

(b) 535 / 746 = **0.72 hp**.

Answer: (a) 535 W (b) 0.72 hp

Common error: Forgetting to divide by time. Power is a rate — the same climb done slower is less power.

6 — Power on an incline at constant speed

At constant speed the engine balances gravity's component plus resistance.

$mg \sin 6° = 1200 \times 9.8 \times 0.10453 = 1229.3$ N; total force $= 1229.3 + 500 = 1729.3$ N.

$P = F v = 1729.3 \times 20 =$ **34,586 W** ≈ 34.6 kW.

Answer: ≈ 34,586 W (34.6 kW)

Common error: Including only gravity or only resistance. At constant speed the engine overcomes both at once.

7 — Kinetic and potential energy

(a) At the top all KE became PE: $\frac{1}{2}mv^2 = mgh \rightarrow v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 28} =$ **23.4 m/s**. Initial KE = $mgh = 0.145 \times 9.8 \times 28 =$ **39.8 J**.

(b) Half the speed is a quarter of the KE (KE $\propto v^2$), so ¾ of the energy is now PE.

Height = $\frac{3}{4} \times 28 =$ **21.0 m**.

Answer: (a) 23.4 m/s, 39.8 J (b) 21.0 m

Common error: Assuming half the speed means half the height. Because KE depends on v squared, half speed is ¼ the KE, so the ball is ¾ of the way up.

8 — Efficiency links effort to load

A single movable pulley has IMA = 2. AMA = efficiency × IMA = $0.88 \times 2 = 1.76$.

Load = AMA × effort = $1.76 \times 34 = 59.84$ N. Mass = $59.84 / 9.8 =$ **6.11 kg**.

Answer: 6.11 kg

Common error: Using IMA instead of AMA (gives 6.94 kg). Real force savings is always less than ideal because of friction.

9 — Block and tackle (5 strands)

(a) IMA = strands = **5**. Load = $250 \times 9.8 = 2450$ N.

(b) Ideal effort = $2450/5 =$ **490 N**.

(c) AMA = $0.78 \times 5 = 3.9 \rightarrow$ actual effort = $2450/3.9 =$ **628.2 N**.

(d) Rope pulled = $5 \times 3.0 =$ **15 m**; work in = $628.2 \times 15 =$ **9423 J** (check: $2450 \times 3 / 9423 = 0.78$ ✓).

Answer: (a) 5 (b) 490 N (c) 628.2 N (d) 15 m, 9423 J

Common error: Using the ideal effort to find work input. Real work input uses the larger actual effort.

10 — Block and tackle (6 strands)

IMA = 6, load = 400 × 9.8 = 3920 N. AMA = 0.72 × 6 = 4.32.

(a) Actual effort = 3920 / 4.32 = **907.4 N**.

(b) Rope pulled = 6 × 2.0 = 12 m; work in = 907.4 × 12 = **10,889 J**.

(c) Useful work out = 3920 × 2.0 = 7840 J, so lost = 10,889 − 7840 = **3049 J**.

Answer: (a) 907.4 N (b) 10,889 J (c) 3049 J lost

Common error: Forgetting the rope moves 6× the load distance. More strands means more rope pulled, not less.

11 — Ramp as a machine: IMA vs AMA

(a) IMA = length/height = 4.0/1.2 = **3.33**. Load = 588 N.

(b) AMA = 588/220 = **2.67**. (c) efficiency = 2.67/3.33 = **80.2%**.

(d) Energy lost = (220×4.0) − (588×1.2) = 880 − 705.6 = **174.4 J**.

Answer: (a) 3.33 (b) 2.67 (c) 80.2% (d) 174.4 J lost

Common error: Using ramp length as the height in IMA, or flipping efficiency to IMA/AMA (which would exceed 100%).

12 — Ramp machine with power

(a) IMA = 5.0/2.0 = **2.5**. Load = 80 × 9.8 = 784 N.

(b) Ideal effort = 784/2.5 = **313.6 N**.

(c) AMA = 0.68 × 2.5 = 1.7 → actual effort = 784/1.7 = **461.2 N**.

(d) Work in = 461.2 × 5.0 = **2306 J** (check: 784×2.0 / 0.68 = 2306 ✓).

(e) Power = 2306 / 8.0 = **288 W**.

Answer: (a) 2.5 (b) 313.6 N (c) 461.2 N (d) 2306 J (e) 288 W

Common error: Computing power from useful work only. Your power output is the work you actually put in divided by time.

AUX — Free Physics Resources · auxlearning.com · g = 9.8 m/s^2 throughout