Power

Unit: Work, Energy & Momentum

NGSS Standards: N/A

MA Curriculum Frameworks (2006): 2.4

AP Physics 1 Learning Objectives: N/A, but power problems have appeared on the AP exam.

Skills:
- calculate power

Language Objectives:
- Understand and correctly use the term “power.”
- Accurately describe and apply the concepts described in this section using appropriate academic language.
- Set up and solve word problems involving power.

Notes:
power: a measure of the rate at which energy is applied or work is done. Power is calculated by dividing work (or energy) by time.

\[
P = \frac{\Delta W}{t} = \frac{\Delta K}{t} = \frac{\Delta U}{t}
\]

Power is a scalar quantity and is measured in Watts (W).

\[1 \text{ W} = 1 \frac{\text{J}}{\text{s}} = 1 \frac{\text{N} \cdot \text{m}}{\text{s}} = 1 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^3}\]

Note that utility companies measure energy in kilowatt-hours. This is because \( P = \frac{W}{t} \), which means energy = \( W = Pt \).

Because 1 kW = 1000 W and 1 h = 3600 s, this means 1 kWh = (1000 W)(3600 s) = 3600000 J

Because \( W = Fd \), this means \( P = \frac{Fd}{t} = F \left( \frac{d}{t} \right) = Fv \)

Use this space for summary and/or additional notes.
Power in Rotational Systems

In a rotational system, the formula for power looks similar to the equation for power in linear systems, with force replaced by torque and linear velocity replaced by angular velocity:

\[ P = Fv \quad P = \tau \omega \]

linear rotational

Solving Power Problems

Many power problems require you to calculate the amount of work done or the change in energy, which you should recall is:

\[ W = Fd \quad \text{if the force is caused by linear displacement} \]
\[ W = \tau \Delta \theta \quad \text{if the work is produced by a torque} \]
\[ \Delta K_t = \frac{1}{2} m(v^2 - v_0^2) \quad \text{if the change in energy was caused by a change in velocity} \]
\[ \Delta K_r = \frac{1}{2} I(\omega^2 - \omega_0^2) \quad \text{if the change in energy was caused by a change in angular velocity} \]
\[ \Delta U_g = mg \Delta h \quad \text{if the change in energy was caused by a change in height} \]

Once you have the work or energy, you can plug it in for either \( W, \Delta E_k \) or \( \Delta U \), use the appropriate parts of the formula:

\[ P = \frac{W}{t} = \frac{\Delta K}{t} = \frac{\Delta U}{t} = Fv = \tau \omega \]

and solve for the missing variable.

Use this space for summary and/or additional notes.
Sample Problems

Q: What is the power output of an engine that pulls with a force of 500. N over a distance of 100. m in 25 s?

A: \[ W = Fd = (500)(100) = 50000 \text{ J} \]
\[ P = \frac{W}{t} = \frac{50000}{25} = 2000 \text{ W} \]

Q: A 60. W incandescent light bulb is powered by a generator that is powered by a falling 1.0 kg mass on a rope. Assuming the generator is 100% efficient (i.e., no energy is lost when the generator converts its motion to electricity), how far must the mass fall in order to power the bulb at full brightness for 1.0 minute?

A: \[ P = \frac{\Delta U_g}{t} = \frac{mg \Delta h}{t} \]
\[ 60 = \frac{(1)(10) \Delta h}{60} \]
\[ 3600 = 10 \Delta h \]
\[ \Delta h = \frac{3600}{10} = 360 \text{ m} \]

Note that 360 m is approximately the height of the Empire State Building. This is why changing from incandescent light bulbs to more efficient compact fluorescent or LED bulbs can make a significant difference in energy consumption!
Homework Problems

1. A small snowmobile has a 9000 W (12 hp) engine. It takes a force of 300 N to move a sled load of wood along a pond. How much time will it take to tow the wood across the pond if the distance is measured to be 850 m?

Answer: 28.3 s

2. A winch, which is rated at 720 W, is used to pull an all-terrain vehicle (ATV) out of a mud bog for a distance of 2.3 m. If the average force applied by the winch is 1500 N, how long will the job take?

Answer: 4.8 s

3. What is your power output if you have a mass of 65 kg and you climb a 5.2 m vertical ladder in 10.4 s?

Answer: 325 W
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<td>4.</td>
<td>Jack and Jill went up the hill. (The hill was 23m high.) Jack was carrying a 21 kg pail of water. If Jack has a mass of 75 kg and he made the trip in 45 s, how much power did he apply?</td>
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<td>Answer: 490.7 W</td>
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<td>5.</td>
<td>Jill, who has a mass of 55 kg, made the same trip as Jack did in problem #3, but she took 10 seconds less. How much power did she apply?</td>
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<td>Answer: 499.4 W</td>
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<td>6.</td>
<td>The maximum power output of a particular crane is 12 kW. What is the fastest time in which this crane could lift a 3500 kg crate to a height of 6.0 m?</td>
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<td>Answer: 17.5 s</td>
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<td>7.</td>
<td>The maximum power output of a particular crane is P. What is the fastest time, t, in which this crane could lift a crate with mass m to a height h? (You may use your work from problem #6 above to guide your algebra.)</td>
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<td>Answer: $t = \frac{mgh}{P}$</td>
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Use this space for summary and/or additional notes.
8. A 30 cm diameter solid cylindrical flywheel with a mass of 2500 kg was accelerated from rest to an angular velocity of 1800 RPM in 60 s.
   a. How much work was done on the flywheel?

   Answer: \(5.0 \times 10^5\) N·m

   b. How much power was exerted?

   Answer: \(8.3 \times 10^3\) W