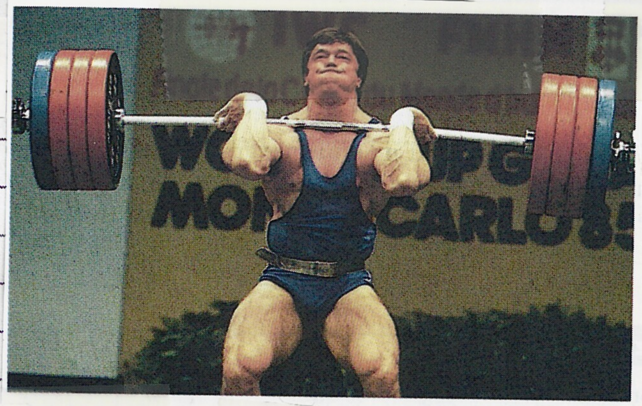
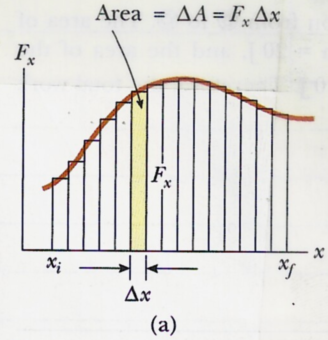
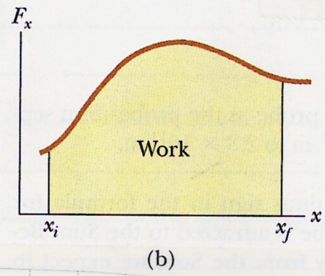
chapter 7



The weightlifter does no work on the weights as he holds them on his shoulders.





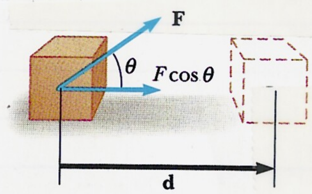
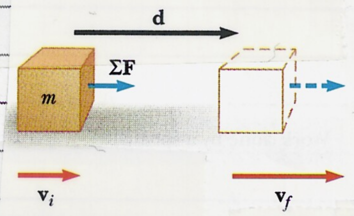
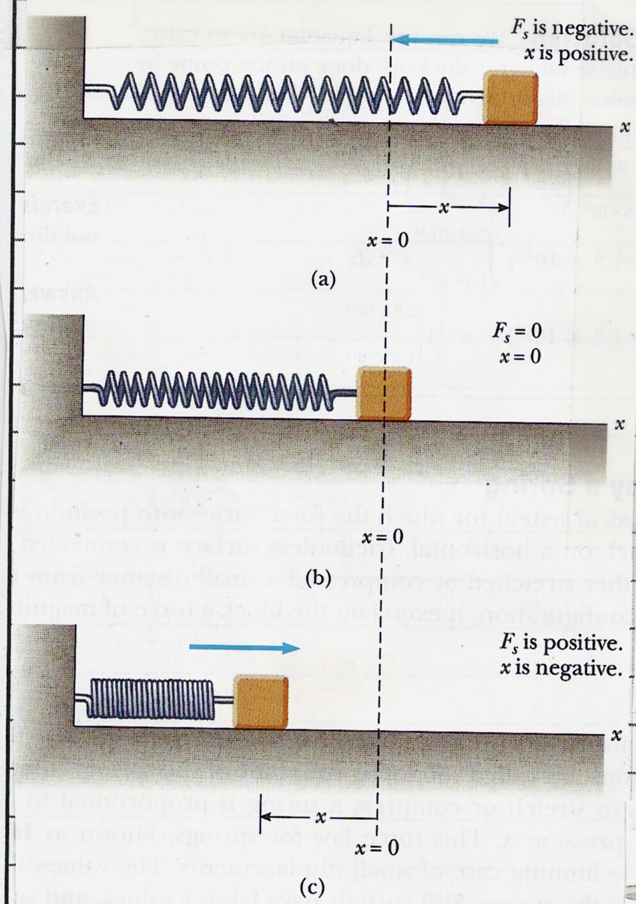


Figure 7.2 If an object undergoes a displacement **d** under the action of a constant force **F**, the work done by the force is $(F\cos\theta)\,d$.

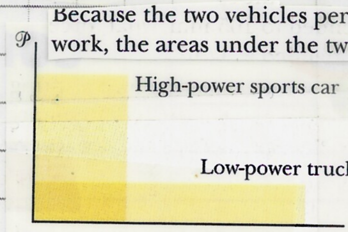


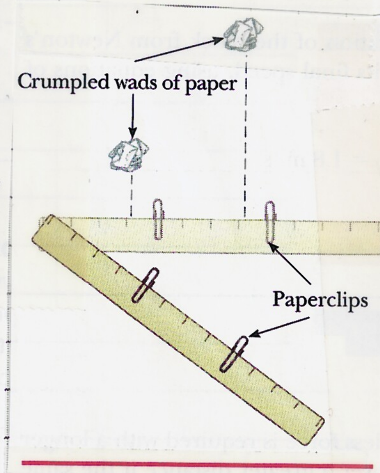
$$\sum W = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2$$

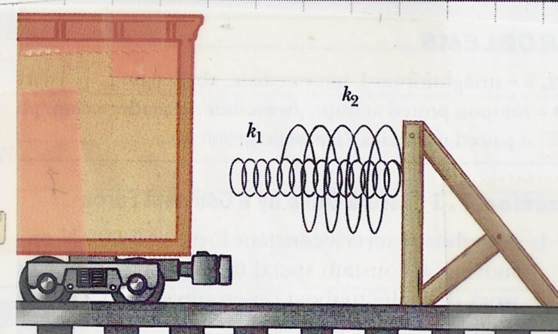
$$W = \int_{x_i}^{x_f} F_x\,dx$$

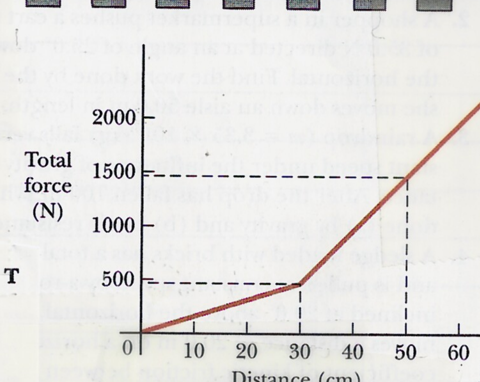


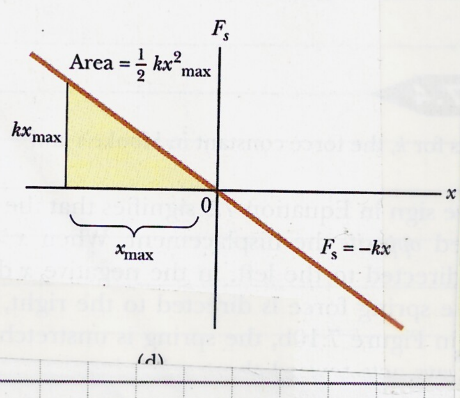
Because the two vehicles perform the same amount of work, the areas under the two graphs are equal.

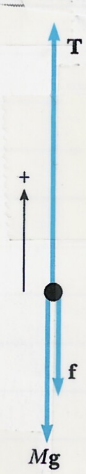


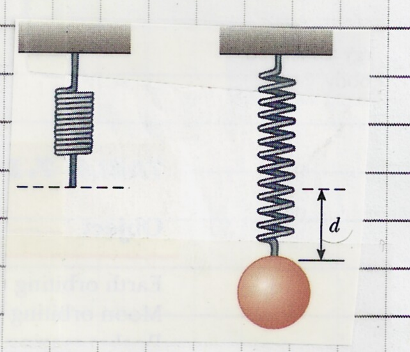






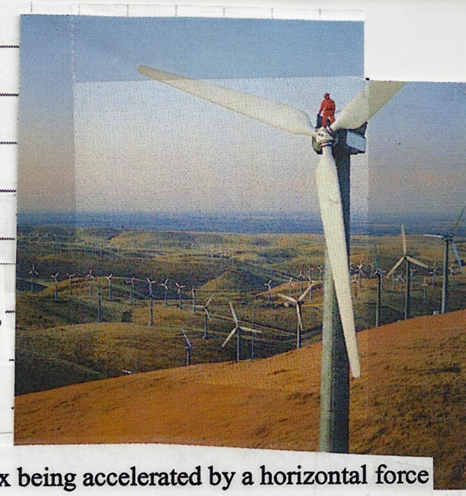






Chapter 7

Energy and Energy Transfer



CHAPTER OUTLINE

7.1 Work Done by a Constant Force

Q1: What is the definition of work when the force acting is constant?

Q3: How much work is done by gravity and the normal force on a box being accelerated by a horizontal force surface?

Q4a: Watch me easily lift the barbell with a constant velocity. How much work am I doing in the lift?

Q4b: How much work did the gravitational force do when I lifted the barbell?

Q5: Is work a scalar or a vector?

Q6a: What are the units of work?

Q6b: What is the cgs system? What are the units of work in the cgs system?

Q6c: How many ergs are in a joule?

Q6d: What are the units of work in the British engineering system?

P1: An object is being pulled along the ground by a 75 N force directed 28° above the horizontal. How much work does the force do in pulling the object 8.0 m?

P2: Going back to the barbell; Now I will lift the barbell at a steady rate and then walk with it at a steady rate. Determine the work done by me on the barbell and by the force of gravity on the barbell. Determine the net work done on the barbell.

P3: A 300. g object slides 80.0 cm along a horizontal tabletop. How much work is done in overcoming friction between the object and the table if the coefficient of kinetic friction is 0.20? Is this work positive or negative?

Q8a: As a pendulum swings back and forth as demonstrated by Askey, does the tension in the string do any work on the pendulum bob?

Q8b: Does the force of gravity do any work? explain

P4: A truck is dragging a stalled car up a 20° incline. The tensile force on the towline is constant, and the two vehicles accelerate at a constant rate. If the cable makes an angle of 30° with the road and the tension is 1600 N, how much work was done by the truck on the car in pulling it 0.50 km up the incline?

Chapter 7: Energy and Energy Transfer: Class Notes

The Scalar Product (Dot Product) of Two Vectors

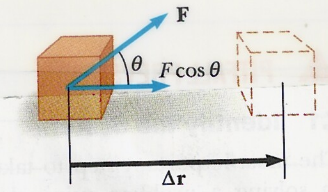


Figure 7.2 If an object undergoes a displacement **Δr** under the action of a constant force **F**, the work done by the force is $F\Delta r \cos\theta$.

Q10: What is meant by the scalar product of two vectors?

Q11: Why is this called the dot product?

TRANSPARENCY 7.6 notes:

Q12: Do the units of A and B have to be the same?

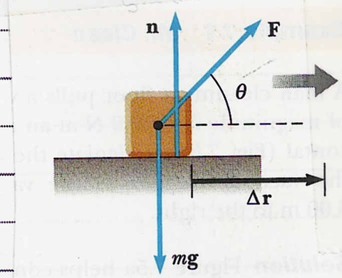


Figure 7.3 When an object is displaced on a frictionless, horizontal surface, the normal force **n** and the gravitational force $m\mathbf{g}$ do no work on the object. In the situation shown here, **F** is the only force doing work on the object.

Q13: How about the commutative and distributive laws of multiplication?

Q14: What is A · B if vectors A and B are parallel?

Q15: What is A · B if vectors A and B are perpendicular?

Q16a: What is the value of i · i, j · j, k · k ?

Q16b: What is the value of i · j, i · k, j · k ?

P5a: The vectors A and B are given by A = 2i + 3j and B = -i + 2j.
Determine the scalar product A · B

P5b: Find the angle between A and B

P6: Vector A extends from the origin to a point having polar coordinates (7,70°) and vector B extends from the origin to a point having polar coordinates (4,130°). Find A · B.
Required drawing:

P7a: A particle moving in the xy plane undergoes a displacement s = (2.0i + 3.0j) m while a constant force F = (5.0i + 2.0j) N acts on the particle. Calculate the magnitude of the displacement and that of the force.
Required drawing: (Also find the angle between them.)

P7b: Calculate the work done by F by using unit vectors.

Q17: Let's go back and pick up a little more calculus before we move on. What is the derivative of sin x?

Q18: What is the derivative of cos x?

Q19: Graphically, show why this is the case

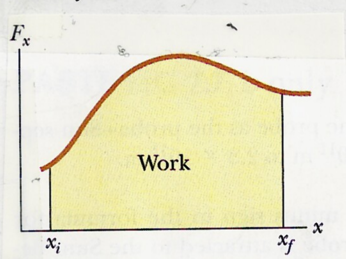
Chapter 7: Energy and Energy Transfer: Class Notes

Work Done by a Varying Force

Q20: Consider a particle being displaced along the x axis under the action of a varying force, as in Transparency 7.7a. Why can't we use the equation $W = Fx\cos\theta$ to find the work done?

Q21a: Go through the steps to show how the integral equation for work is derived.

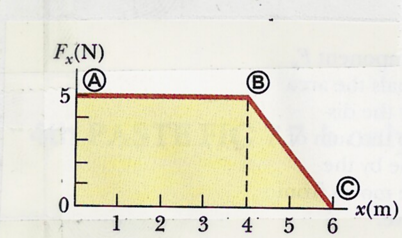
Q21b.) Write the general equation you would use to determine the work (represented by the graph below) done on an object.



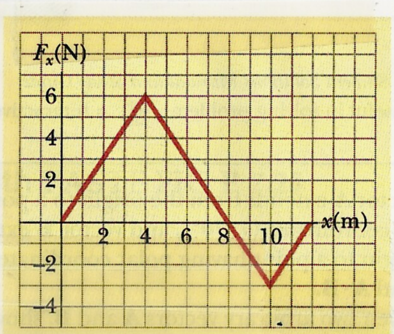
(b)

Note: If more than one force acts on a particle, the total work done is just the work done by the resultant force. In this case the net work done as the particle moves from x_i to x_f is . . ..

P8: A force acting on a particle varies with x as shown in figure below. Calculate the work done by the force as the particle moves from x = 0 to x = 6.0 m.



P9: The force acting on a particle varies as in the figure below. Find the work done in these displacements:
a.) x = 0 to x = 8 m b.) x = 8.0 m to x = 12 m c.) x = 0 m to x = 12 m

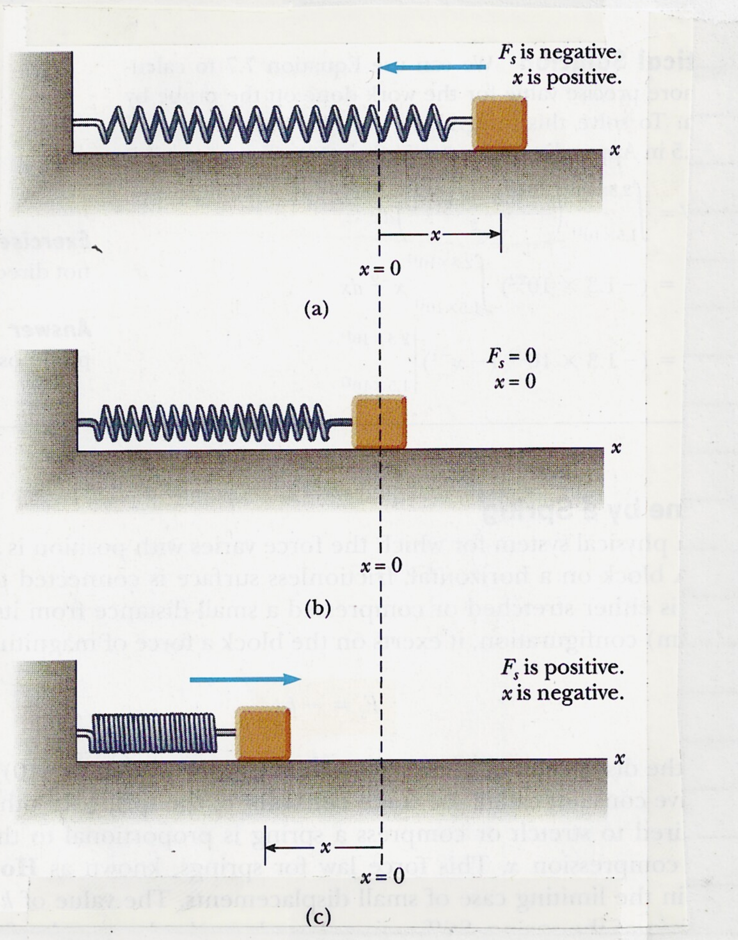


Chapter 7: Energy and Energy Transfer: Class Notes

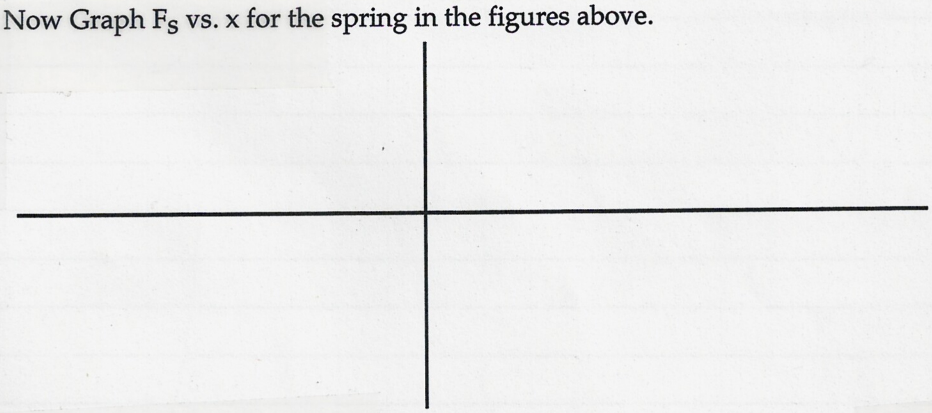
P10: The force acting on a particle varies as a function of position with the following equation: $F(x) = 5x^2 + 2x$.
a.)Determine the general equation for the amount of work done by this force over position.
b.) Assuming that 10N of force is applied to the object at the very beginning of the push, determine the amount of work done from x=7m to x=12 m.

P11: A force $F = (6x\mathbf{i} + 5y\mathbf{j})$ N acts on an object as it moves in the y direction from the origin to y = 3.00 m. Find the work done on the object by the force.

Q25: We are going to have to look at this restoring force in more detail by working over this figure below.



P13: Now Graph F_s vs. x for the spring in the figures above.



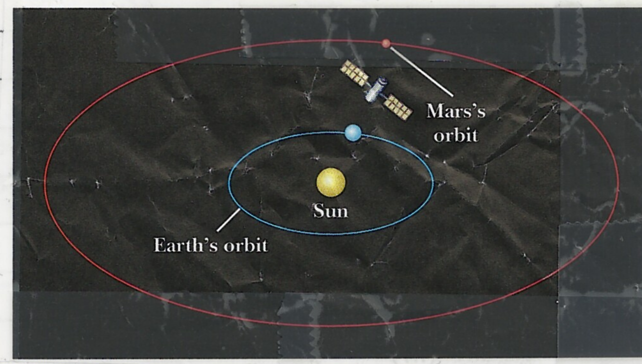
P14: Use the graph and what you know about integrals to determine the work done by the spring on the block.

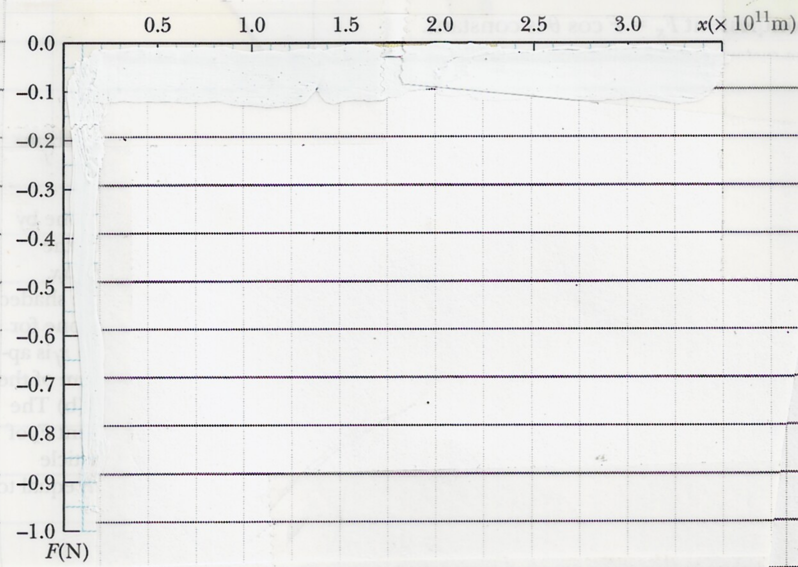
Chapter 7: Energy and Energy Transfer: Class Notes

The interplanetary probe shown in Figure 7.9a is attracted to the Sun by a force given by

$$F = -\frac{1.3 \times 10^{22}}{x^2}$$

in SI units, where x is the Sun-probe separation distance. Graphically and analytically determine how much work is done by the Sun on the probe as the probe–Sun separation changes from 1.5×10^{11} m to 2.3×10^{11} m.





Q26a: Show through integrals the derivation of the equation for the potential energy (U_s) of a spring with the compressed displacement $-x_m$.

Q26b: Is the work done by the spring positive or negative?

P15: Using that same drawing of a spring scale, determine the work done by the spring on the block as the block goes from 0 to $+x_m$.

P16: What is the net work done by the spring as the block moves from $+x_{max}$ to $-x_{max}$?

P17: What is the net work done by the ~~block~~ spring in an arbitrary displacement from $x = x_i$ to $x = x_f$?

P19: A toy dart gun utilizes a spring with a spring constant of 60 N/m. How much work must be done to compress this spring a distance of 3.2 cm?

Plot it.

Chapter 7: Energy and Energy Transfer: Class Notes

P21: Now derive the Work - Kinetic Energy Theorem in a more general way starting with the integral equation for work and using substitution and the chain rule.

Q28a: So, in general, how can we relate kinetic energy of a particle to the work of that particle?

Long descriptive way ===>

Short pocketbook way ===>

Q29: Check out these Kinetic Energies:

TABLE 7.1 Kinetic Energies for Various Objects

Object	Mass (kg)	Speed (m/s)	Kinetic Energy (J)
Earth orbiting the Sun	5.98×10^{24}	2.98×10^{4}	2.65×10^{33}
Moon orbiting the Earth	7.35×10^{22}	1.02×10^{3}	3.82×10^{28}
Rocket moving at escape speed[a]	500	1.12×10^{4}	3.14×10^{10}
Automobile at 55 mi/h	2 000	25	6.3×10^{5}
Running athlete	70	10	3.5×10^{3}
Stone dropped from 10 m	1.0	14	9.8×10^{1}
Golf ball at terminal speed	0.046	44	4.5×10^{1}
Raindrop at terminal speed	3.5×10^{-5}	9.0	1.4×10^{-3}
Oxygen molecule in air	5.3×10^{-26}	500	6.6×10^{-21}

[a] *Escape speed* is the minimum speed an object must attain near the Earth's surface if it is to escape the Earth's gravitational force.

P23.) If it takes 4.00 J of work to stretch a Hooke's law spring 10.0 cm from its unstressed length, determine the extra work required to stretch it an additional 10.0 cm.

P24.) A 3.00 kg mass has an initial velocity vi = (6.00i - 2.00j) m/s.
a.) What is its kinetic energy at this time?
b.) Find the total work done on the object if its velocity changes to (8.00i + 4.00j) m/s

Chapter 7: Energy and Energy Transfer: Class Notes

P25.) In a rifle barrel, a 15.0 g bullet is accelerated from rest to a speed of 780 m/s.
a.) Find the work that is done on the bullet.
b.) If the rifle barrel is 72.0 cm long, find the magnitude of the average total force that acted on it,

P26a: A 6.0 kg block initially at rest is pulled to the right along a horizontal, frictionless surface by a constant, horizontal force of 12 N. Find the speed of the block after it has moved 3.0 m. SKIP A: GO to B.

P26b: Find the final speed of the block described in (a) if the surface is rough and the coefficient of kinetic friction is 0.15.

Mini Demo: Askey will demonstrate a little speed vs. K using wads of paper, paper clips and a ruler.

P33: A block of mass 2.0 kg is attached to a spring that has a force constant of 500 N/m as in Transparency 7.10. The block is pulled 5.00 cm to the right of equilibrium and is then released from rest. Find the speed of the block as it passes through equilibrium if

[redacted]

(b) the coefficient of friction between the surface and the block is 0.350.

7.5 Power

Q35: How is power related to work (energy)?

Q36: What is the equation for average power?

Note: Power is also called the "time rate of energy transfer."

Q37: What is the equation for instantaneous power?

Q38: Now use this equation and what you know about work to write an equation in which Power is related to force and velocity.

Q39: What is the SI unit for power? What is its symbol?

Chapter 7: Energy and Energy Transfer: Class Notes

Q40: What is this in terms of kg, m and s?

Q41: What is the British engineering system unit for power?

Q42: What is the conversion between this and watts?

Q43: What is a kilowatt hour (kWh)?

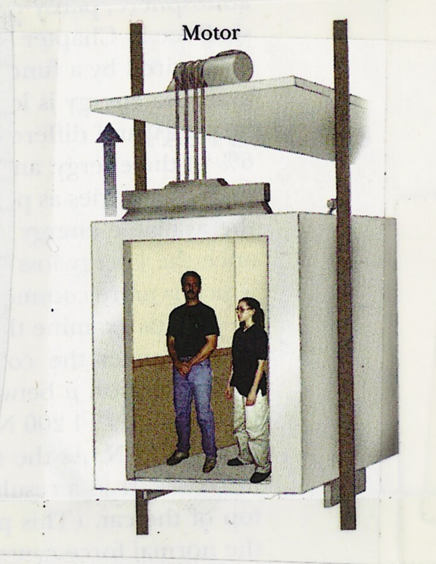
Q44: How many joules are in a kWh?

Q45: Is a kWh a unit of energy or power?

Q46: How much energy (in MJ) does a light bulb rated at 100 W consume in 3 hours?

P28: A 1500-kg car accelerates uniformly from rest to 10 m/s in 3.0 sec. Find
a.) the work done on the car in this time.
b.) the average power delivered by the engine in the first 3.0 s
c.) the instantaneous power delivered by the engine at t=2.0 sec.

P29a: An elevator has a mass of 1000. kg and carries a maximum load of 800. kg. A constant frictional force of 4000. N retards its motion upward. (Askey will draw a picture if you want him to.)
a.) What must be the minimum power delivered by the motor to lift the elevator at constant speed of 3.00 m/s?
b.) What power must the motor deliver at any instant if it is designed to provide an upward acceleration of 1.00 m/s^2? answer in terms of v.



P29b: In the above problem, the motor delivers power to lift the elevator, yet the elevator moves at a constant speed. A student analyzing this situation claims that according to the work energy theorem, if the speed of the elevator remains constant, the work done on it is zero. The student concludes that the power that must be delivered by the motor must also be zero. How could you explain this apparent paradox?

Energy and the Automobile

Q47: How much available energy in the fuel that goes into your tank actually is used to propel your vehicle?

Q48: So where does all the rest of the energy go?

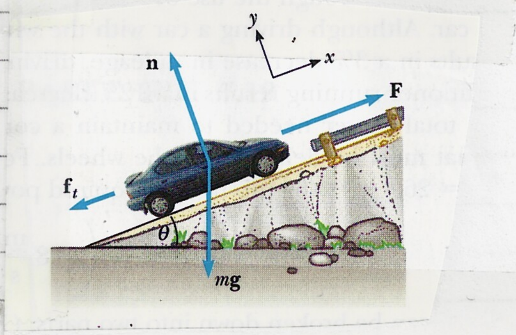
TABLE 7.2 **Frictional Forces and Power Requirements for a Typical Car**[a]

v (m/s)	n (N)	f_r (N)	f_a (N)	f_t (N)	$\mathcal{P} = f_t v$ (kW)
0	14 200	227	0	227	0
8.9	14 100	226	51	277	2.5
17.8	13 900	222	204	426	7.6
26.8	13 600	218	465	683	18.3
35.9	13 200	211	830	1 041	37.3
44.8	12 600	202	1 293	1 495	67.0

[a] In this table, n is the normal force, f_r is road friction, f_a is air friction, f_t is total friction, and $\mathcal{P}$ is the power delivered to the wheels.

P30: A compact car has a mass of 800 kg, and its efficiency is rated at 18%. (That is, 18% of the available fuel energy is delivered to the wheels.) Find the amount of gasline used to accelerate the car from rest to 60. mi/hr (27 m/s). Use the fact that the energy equivalent of one gallon of gasoline is 1.3×10^8 J

P31a: Consider a car of mass m that is accelerating up a hill. An automotive engineer has measured the megnitude of the total resistive force to be $f_t = (218 + 0.70v^2)$ N where v is the speed in meters per second. Determine the equation for power the engine must deliver to the wheels as a function of speed and explain what each term means.



P31b: For the above problem: Plug in 1450 kg for mass, 27 m/s (=60 mph) for velocity, 1.0 m/s^2 for acceleration, and 10° for the incline. Determine the value of the four terms in the power equation both in kW and horsepower and determine the overall power in kW and horsepower.

[redacted]