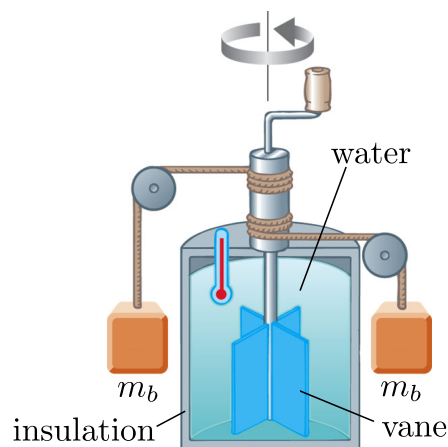
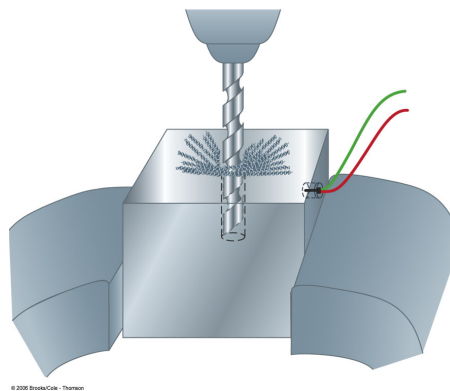


## Homework 1 Temperature, Heat, and Energy\*

- Legend has it that on his honeymoon, James Joule traveled from England to Switzerland. He attempted to verify his idea of the interconvertibility of mechanical energy and internal energy by measuring the increase in temperature of water that fell in a waterfall. For the waterfall near Chamonix in the French Alps, which has a 120-m drop, what maximum temperature rise could Joule expect? He did not succeed in measuring it, partly because evaporation cooled the falling water and also because his thermometer was not sufficiently sensitive.
- James Joule's apparatus to measure the mechanical equivalent of heat is shown in the figure. When the two weights, each of mass  $m_b$ , are released they unwind the rope which turns an axle rotating the vanes and heating the liquid. The mass of each of the two blocks is  $m_b = 1.50 \text{ kg}$ , and the insulated tank is filled with  $m_w = 0.2 \text{ kg}$  of water. What is the increase in the temperature of the water after the blocks fall through a distance of  $\Delta y = 3.0 \text{ m}$ ?

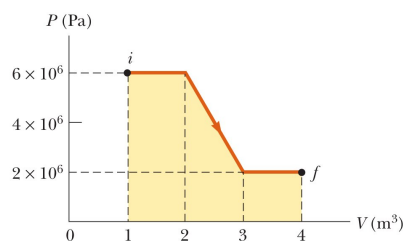


- A 50.0-g sample of copper is at  $25.0^\circ\text{C}$ . If 1200 J of energy is added to it by heat, what is the final temperature of the copper?
- A 1.50-kg iron horseshoe initially at  $600^\circ\text{C}$  is dropped into a bucket containing 20.0 kg of water at  $25.0^\circ\text{C}$ . What is the final temperature? (Ignore the heat capacity of the container and assume that a negligible amount of water boils away.)
- A drill is used to make a hole in a steel cube. The drill bit used is also made of steel with a mass  $m_b = 0.027 \text{ kg}$  and diameter  $d = 0.635 \text{ cm}$ . The mass of the cube is  $m_c = 0.240 \text{ kg}$ . Assume steel has the same properties as iron. The cutting process can be modeled as happening at one point on the circumference of the bit. This point on the bit moves in a helix at constant speed  $v_b = 40.0 \text{ m/s}$  with a force of constant magnitude  $F_b = 3.20 \text{ N}$  on the block. As shown in the figure, a groove in the bit carries the chips up to the top of the block, where they form a pile around the hole. The block is held in a clamp made of material of low thermal conductivity, and the drill bit is held in by a device known as a chuck which is also made of this material. We consider turning the drill on for a time interval of  $\Delta t = 15.0 \text{ s}$ . This time interval is short enough so the steel objects lose a negligible amount of energy into their environment, but it is long enough for conduction in the steel to bring it the bit, the block, and the chips to a uniform temperature. The temperature is measured with a thermometer probe on the side of the block. (a) First suppose the drill bit is sharp and cuts three quarters of the way through the block during  $\Delta t$ . Find the temperature change of the whole quantity of steel (the bit, the block, and the chips). (b) Now suppose the drill bit is dull and cuts only one eighth of the way through the block during  $\Delta t$ . Identify the temperature change of the whole quantity of steel in this case (the bit, the block, and the chips).



\* See *Thermodynamic Quantities* at the end of this section for tables of constants.

6. How much energy is required to change a 40.0-g ice cube from ice at  $-10.0^{\circ}\text{C}$  to steam at  $110^{\circ}\text{C}$ ?
7. A 3.00-g lead bullet at  $30.0^{\circ}\text{C}$  is fired at a speed of 240 m/s into a large block of ice at  $0^{\circ}\text{C}$ , in which it becomes embedded. What quantity of ice melts?
8. Two identical cars collide head-on while each is traveling at a speed  $v = 20 \text{ m/s}$ . Suppose all their kinetic energy is transformed into the thermal energy of the wrecks. What is the temperature increase  $\Delta T$  of each car? You can assume that each car's specific heat is that of iron which is  $c = 450 \text{ J/kg} \cdot ^{\circ}\text{C}$ .
9. An aluminum cup of mass 200 g contains 800 g of water in thermal equilibrium at  $80.0^{\circ}\text{C}$ . The combination of cup and water is cooled uniformly so that the temperature decreases by  $1.50^{\circ}\text{C}$  per minute. At what rate is energy being removed by heat? Express your answer in watts.
10. An aluminum calorimeter with a mass of 100 g contains 250 g of water. The calorimeter and water are in thermal equilibrium at  $10.0^{\circ}\text{C}$ . Two metallic blocks are placed into the water. One is a 50.0-g piece of copper at  $80.0^{\circ}\text{C}$ . The other block has a mass of 70.0 g and is originally at a temperature of  $100^{\circ}\text{C}$ . The entire system stabilizes at a final temperature of  $20.0^{\circ}\text{C}$ . What is the specific heat of the unknown sample?
11. If water with a mass  $m_h$  at temperature  $T_h$  is poured into an aluminum cup of mass  $m_{Al}$  containing mass  $m_c$  of water at  $T_c$ , where  $T_h > T_c$ , what is the equilibrium temperature of the system?
12. A 50.0-g copper calorimeter contains 250 g of water at  $20.0^{\circ}\text{C}$ . How much steam must be condensed into the water if the final temperature of the system is to reach  $50.0^{\circ}\text{C}$ ?
13. A block of copper of mass  $m = 2.0 \text{ kg}$  at  $T_0 = 20^{\circ}\text{C}$  is dropped into a large vessel of liquid nitrogen at  $T_1 = 77.3 \text{ K}$ . How many kilograms of nitrogen boil away before the copper reaches the temperature  $T_1$ ? (The specific heat of copper is  $0.0920 \text{ cal/g} \cdot ^{\circ}\text{C}$ . The latent heat of vaporization of nitrogen is  $48.0 \text{ cal/g}$ .)
14. What mass of steam at  $T_0 = 100^{\circ}\text{C}$  must be mixed with a mass  $m_1 = 0.20 \text{ kg}$  of ice at its melting point in a thermally insulated container to produce liquid water at  $T_1 = 60^{\circ}\text{C}$ ?
15. Assume that a hailstone at  $0^{\circ}\text{C}$  falls through air at a uniform temperature of  $0^{\circ}\text{C}$  and lands on a sidewalk also at this temperature. From what initial height must the hailstone fall to entirely melt on impact?
16. Two speeding lead bullets, each of mass 5.00 g and at temperature  $20.0^{\circ}\text{C}$ , collide head-on at speeds of 500 m/s each. Assuming a perfectly inelastic collision and no loss of energy by heat to the atmosphere, describe the final state of the two-bullet system.
17. What is the work done on a fluid that expands from the point  $i$  to  $f$  as shown in the figure? How much work is performed on the fluid if it is compressed from  $f$  to  $i$  along the same path?

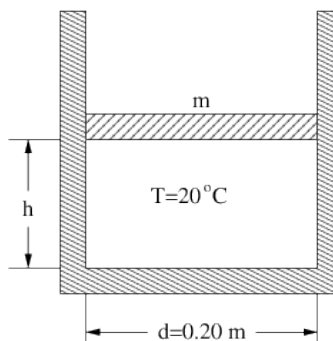


18. A thermodynamic system undergoes a process in which its internal energy decreases by 500 J. At the same time, 220 J of work is done on the system. Find the energy transferred to or from it by heat.
19. A student obtains the following data in a calorimetry experiment designed to measure the specific heat of aluminum:

Initial temperature of water and calorimeter	$70^{\circ}\text{C}$
Mass of water	0.400 kg
Mass of calorimeter	0.040 kg
Specific heat of calorimeter	$0.63 \text{ kJ/kg} \cdot ^{\circ}\text{C}$
Initial temperature of aluminum	$27^{\circ}\text{C}$
Mass of aluminum	0.200 kg
Final temperature of mixture	$66.3^{\circ}\text{C}$

Use these data to determine the specific heat of aluminum. How close is it to the expected value?

20. A 670-kg meteorite happens to be composed of aluminum. When it is far from the Earth, its temperature is  $-15^{\circ}\text{C}$  and it moves with a speed of 14.0 km/s relative to the Earth. As it crashes into the Earth, assume that the resulting additional internal energy is shared equally between the meteor and the planet, and that all the material of the meteor rises momentarily to the same final temperature. Find this temperature. Assume that the specific heat of liquid and of gaseous aluminum is  $1170 \text{ J/kg} \cdot ^{\circ}\text{C}$ .
21. A pitcher throws a 0.142-kg baseball at 47.2 m/s. As it travels 19.4 m, the ball slows to 42.5 m/s because of air resistance. Find the change in temperature of the air through which it passes. To find the greatest possible temperature change, you may make the following assumptions. Air has a molar specific heat of  $C_P = 7R/2$  and an equivalent molar mass of 28.9 g/mol. The process is so rapid that the cover of the baseball acts as thermal insulation, and the temperature of the ball itself does not change. A change in temperature happens initially only for the air in a cylinder 19.4 m in length and 3.70 cm in radius. This air is initially at  $20.0^{\circ}\text{C}$ .
22. On your wedding day your lover gives you a gold ring of mass 3.80 g. Fifty years later its mass is 3.35 g. On the average, how many atoms were abraded from the ring during each second of your marriage? The molar mass of gold is 197 g/mol.
23. Use the definition of Avogadro's number to find the mass of a helium atom.
24. An automobile tire is inflated with air originally at  $10.0^{\circ}\text{C}$  and normal atmospheric pressure. During the process, the air is compressed to 28.0% of its original volume and the temperature is increased to  $40.0^{\circ}\text{C}$ . (a) What is the tire pressure? (b) After the car is driven at high speed, the tire air temperature rises to  $85.0^{\circ}\text{C}$  and the interior volume of the tire increases by 2.00%. What is the new tire pressure (absolute) in pascals?
25. A rigid tank having a volume of  $0.100 \text{ m}^3$  contains helium gas at 150 atm. How many balloons can be inflated by opening the valve at the top of the tank? Each filled balloon is a sphere 0.300 m in diameter at an absolute pressure of 1.20 atm.
26. In state-of-the-art vacuum systems, pressures as low as  $10^{-9} \text{ Pa}$  are being attained. Calculate the number of molecules in a  $1.00 - \text{m}^3$  vessel at this pressure assuming that the temperature is  $27.0^{\circ}\text{C}$ .
27. A room of volume  $V$  contains air having equivalent molar mass  $M$  (in g/mol). If the temperature of the room is raised from  $T_1$  to  $T_2$ , what mass of air will leave the room? Assume that the air pressure in the room is maintained at  $P_0$ .
28. The circular,  $m = 40 - \text{kg}$ , lead piston shown in the figure floats on  $n = 0.1 \text{ mole}$  of compressed air. The diameter of the piston is  $d = 0.2 \text{ m}$ . What is the piston height  $h$  if  $T_0 = 20^{\circ}\text{C}$ ? How much does the height change if you then heat the air inside to  $T_1 = 50^{\circ}\text{C}$ ?



29. A cube  $l = 0.2 \text{ m}$  on a side contains air with an equivalent molar mass  $m_n = 28.9 \text{ g/mole}$  at atmospheric pressure ( $P_0 = 1.01 \times 10^5 \text{ N/m}^2$ ) and  $T = 280 \text{ K}$ . (a) What is the mass of the gas and (b) what is the force it exerts on each face of the cube?
30. How much heat is required to vaporize a piece of ice of mass  $m = 0.1 \text{ kg}$  at  $T_0 = 0^{\circ}\text{C}$ ? The heat of fusion of ice is  $L_f = 3.33 \times 10^5 \text{ J/kg}$ , the heat of vaporization of water is  $L_V = 2.26 \times 10^6 \text{ J/kg}$ , and the specific heat of water is  $c_w = 4186 \text{ J/kg} \cdot ^{\circ}\text{C}$ . Which requires more energy - fusion or vaporization? Explain.

31. A piece of ice of mass  $m_I = 0.02 \text{ kg}$  at  $T_I = 0^\circ\text{C}$  is heated until a mass  $m_w = 0.015 \text{ kg}$  of the original ice has become water at  $T_w = 100^\circ\text{C}$  and the remaining mass has been converted to steam at  $T_w$ . How much heat  $Q$  must be added to do this?
32. A 1-kg block of copper at  $20^\circ\text{C}$  is dropped into a large vessel of liquid nitrogen which is at a temperature of  $77 \text{ K}$ . Assume the vessel containing the liquid absorbs no heat and find the mass of the liquid nitrogen that will boil away by the time the copper reaches  $77 \text{ K}$ . The specific heats of liquid nitrogen and copper are  $879 \text{ J/kg} - ^\circ\text{C}$  and  $387 \text{ J/kg} - ^\circ\text{C}$  respectively and the heat of vaporization of nitrogen is  $2.01 \times 10^5 \text{ J/kg}$ .
33. Water standing in the open at  $T_w = 32^\circ\text{C}$  evaporates because of the escape of some of the surface molecules. The heat of vaporization of water ( $L_V = 2.253 \times 10^6 \text{ J/kg}$ ) is approximately equal to  $n\langle E_{\text{escape}} \rangle$  where  $\langle E_{\text{escape}} \rangle$  is the average energy of the escaping molecules and  $n$  is the number of molecules per kilogram. What is the molar mass of  $\text{H}_2\text{O}$ ? What is  $\langle E_{\text{escape}} \rangle$ ? What is the ratio of  $E_{\text{escape}}$  to the average kinetic energy of the  $\text{H}_2\text{O}$  molecules assuming the molecules in the liquid are related to the temperature the same way they are related to temperature in a gas?
34. One mole of oxygen gas is at a pressure  $P = 6 \text{ atm} = 6.01 \times 10^5 \text{ Pa}$  and a temperature  $T = 27^\circ\text{C}$ , (a) If the gas is heated at constant volume until the pressure triples, what is the final temperature  $T_f$ ? (b) If the gas is heated so that both the pressure and volume are doubled, what is the final temperature  $T_g$ ?
35. A cook puts a mass of water with  $m = 9.0 \text{ g}$  and temperature  $T_i = 10^\circ\text{C}$  in a pressure cooker of volume  $V = 2.0 \text{ L}$  that is warmed to a final temperature  $T_f = 55^\circ\text{C}$ . What is the pressure inside the pressure cooker?

### Thermodynamic Quantities

Substance	$c(\text{J/kg} - \text{K})$
Aluminum	900
Copper	385
Iron	449
Gold	129
Lead	128
Ice	2090
Water	4190
Ethyl alcohol	2400
Beryllium	1825
Silicon	703
Gallium	368
Iridium	1298
Mercury	140

Substance	$T_m (^\circ\text{C})$	$L_f (\text{J/kg})$	$T_b (^\circ\text{C})$	$L_v (\text{J/kg})$
Nitrogen ( $\text{N}_2$ )	-210	$0.26 \times 10^5$	-196	$1.99 \times 10^5$
Ethyl alcohol	-114	$1.09^5$	78	$8.79 \times 10^5$
Mercury ( $\text{N}_2$ )	-39	$0.11 \times 10^5$	357	$2.96 \times 10^5$
Water ( $\text{N}_2$ )	0	$3.33 \times 10^5$	100	$22.6 \times 10^5$
Lead ( $\text{N}_2$ )	328	$0.25 \times 10^5$	1750	$8.58 \times 10^5$