Physics 06-01 Temperature and Thermal Expansion *Name: ______________________*

Common temp scales

- Celsius (centigrade)
  - Water freezes at ______________°C, Water boils at ______________°C
- Fahrenheit
  - Water freezes at ______________°F, Water boils at ______________°F

$$T_C = \frac{5}{9}(T_F - 32)$$

- Kelvin (K)
  - 0 K = ______________ zero
  - ______________ K = 0°C (water freezing), ______________ K = 100°C (water boiling)

$$T_K = T_C + 273.15$$

Convert 30°C to °F and K

- Heat always flows from ______________ object to ______________ object until thermal ______________

Zeroth Law of Thermodynamics

If A and B are in ______________, and B and C are in ______________, then A and C are in ______________

Table 13.2 Thermal Expansion Coefficients at 20°C [1]

Material	Coefficient of linear expansion $\alpha(1/°C)$	Coefficient of $\beta(1/°C)$
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	56×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or Steel	12×10^{-6}	35×10^{-6}
Invar (Nickel-iron alloy)	0.9×10^{-6}	2.7×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Silver	18×10^{-6}	54×10^{-6}
Glass (ordinary)	9×10^{-6}	27×10^{-6}
Glass (Pyrex®)	3×10^{-6}	9×10^{-6}
Quartz	0.4×10^{-6}	1×10^{-6}
Concrete, Brick	$\sim12\times10^{-6}$	$\sim36\times10^{-6}$
Marble (average)	2.5×10^{-6}	7.5×10^{-6}
Liquids		
Ether		1650×10^{-6}
Ethyl alcohol		1100×10^{-6}
Petrol		950×10^{-6}
Glycerin		500×10^{-6}
Mercury		180×10^{-6}
Water		210×10^{-6}
Gases		
Air and most other gases at atmospheric pressure		3400×10^{-6}

Thermal Expansion

- Linear Expansion
  - Expansion in 1-dimension as ______________ changes

$$\Delta L = \alpha L \Delta T$$

A steel bridge is 2 km long. If the temperature when it was built was 21°C (70°F), what length expansion joints are needed to prevent buckling at 43°C (110°F)?

- Bimetallic Strip
  - Made from ______________ strips of ______________ that have different ______________ of linear expansion
  - One side ______________ more than the other causing the strip to ______________
  - Used in automatic ______________ in appliances and ______________
- Area thermal expansion

$$\Delta A = 2\alpha A \Delta T$$

- Volume thermal expansion

$$\Delta V = \beta V \Delta T$$

  - β = coefficient of volume expansion, usually is about ______________

Why do fluids in the car usually have a reservoir tank (radiator, brake fluid, power steering fluid, oil)?

Physics 06-01 Temperature and Thermal Expansion *Name: ______________________*

Water

- Water is ______________
- The volume of water ______________ from 0°C to 4°C
- Then water ______________ from 4°C and up
- Water is the ______________ (least expanded) at 4°C
- As the weather gets cold, the lake water cools and sinks because it becomes more dense pushing the warmer water up
- After all the water is ______________, the ______________ starts to freeze
- Because the 0°C water is ______________ dense than the 4°C water, it ______________
- The ice ______________ and provides insulation for the ______________ water underneath so it does not freeze

Homework

1. The first international standard of length was a metal bar kept at the International Bureau of Weights and Measures. One meter of length was defined to be the distance between two fine lines engraved near the ends of the bar. Why was it important that the bar be kept at a constant temperature?
2. For added strength, many highways and buildings are constructed with reinforced concrete (concrete that is reinforced with embedded steel rods). The coefficient of linear expansion for concrete is the same as that for steel. Why is this important that these two coefficients be the same?
3. When a cold alcohol thermometer is placed in a hot liquid, the column of alcohol goes down slightly before going up. Explain why.
4. Water expands significantly when it freezes: a volume increase of about 9% occurs. As a result of this expansion and because of the formation and growth of crystals as water freezes, anywhere from 10% to 30% of biological cells are burst when animal or plant material is frozen. Discuss the implications of this cell damage for the prospect of preserving human bodies by freezing so that they can be thawed at some future date when it is hoped that all diseases are curable.
5. One method of getting a tight fit, say of a metal peg in a hole in a metal block, is to manufacture the peg slightly larger than the hole. The peg is then inserted when at a different temperature than the block. Should the block be hotter or colder than the peg during insertion? Explain your answer.
6. Does it really help to run hot water over a tight metal lid on a glass jar before trying to open it? Explain your answer.
7. What is the Celsius temperature of a person with a 98.6 °F body temperature? (RW) **37.0 °C**
8. Frost damage to most plants occurs at temperatures of 28.0°F or lower. What is this temperature on the Kelvin scale? (OpenStax 13.2) **271.0 K**
9. A tungsten light bulb filament may operate at 2900 K. What is its Fahrenheit temperature? What is this on the Celsius scale? (OpenStax 13.4) **2600 °C, 4800 °F**
10. The surface temperature of the Sun is about 5750 K. What is this temperature on the Fahrenheit scale? (OpenStax 13.5) **9890 °F**
11. The height of the Washington Monument is measured to be 170 m on a day when the temperature is 35.0°C. What will its height be on a day when the temperature falls to –10.0°C? Although the monument is made of limestone, assume that its thermal coefficient of expansion is the same as marble's ($\alpha = 2.5 \times 10^{-6}$). (OpenStax 13.9) **169.98 m**
12. How much taller does the Eiffel Tower become at the end of a day when the temperature has increased by 15°C? Its original height is 321 m and you can assume it is made of steel ($\alpha = 12 \times 10^{-6}$). (OpenStax 13.10) **0.058 m**
13. How large an expansion gap should be left between steel railroad rails if they may reach a maximum temperature 35.0°C greater than when they were laid? Their original length is 10.0 m. ($\alpha = 12 \times 10^{-6}$) (OpenStax 13.12) **0.0042 m**
14. Most automobiles have a coolant reservoir to catch radiator fluid that may overflow when the engine is hot. A radiator is made of copper ($\beta = 51 \times 10^{-6}$) and is filled to its 16.0-L capacity when at 10.0°C. What volume of radiator fluid will overflow when the radiator and fluid reach their 95.0°C operating temperature, given that the fluid's volume coefficient of expansion is $\beta = 400 \times 10^{-6}$ / °C ? Note that this coefficient is approximate, because most car radiators have operating temperatures of greater than 95.0°C. (OpenStax 13.18) **0.475 L**
15. A commonly used method of fastening one part to another part is called "shrink fitting." A steel rod ($\alpha = 12 \times 10^{-6}, \beta = 35 \times 10^{-6}$) has a diameter of 2.0026 cm, and a flat plate contains a hole whose diameter is 2.0000 cm. The rod is cooled so that if just fits into the hole. When the rod warms up, the enormous thermal stress exerted by the plate hold the rod securely to the plate. By how many Celsius degrees should the rod be cooled? (Cutnell 12.13) **110 °C**

Physics 06-02 Ideal Gas Law and Kinetic Theory Name: ____________

Ideal Gas Law

$$PV = NkT$$

P = absolute pressure (Pa), V = volume (m³), N = number of particles (unitless), k = Boltzmann's constant = $1.38 \times 10^{-23}\ J/K$, T = temperature (K)

- Large number of ____________ in a sample
- Convenient to have a ____________ for a large number of ____________

Mole (mol)

- Actually ____________
- Number of atoms of ____________ in ____________
- Number of atoms per mole = ____________

____________ number $N_A = 6.022 \times 10^{23}\ mol^{-1}$

Number of moles in a sample

$$n = \frac{N}{N_A}$$

n = number of moles, N = number of particles, $N_A = 6.022 \times 10^{23}\ mol^{-1}$

Number of moles can be found from mass

$$n = \frac{m}{molar\ mass}$$

n = number of moles, m = mass of sample (g), molar mass = same number as atomic mass from periodic table (g/mol)

Ideal Gas Law (moles)

$$PV = nRT$$

P = absolute pressure (Pa), V = volume (m³), n = number of moles (mol), R = universal gas constant (8.31 J/mol· K) = $N_A k$, T = temperature (K)

Kinetic Theory

T is average ____________ of molecules

$$PV = NkT = \frac{1}{3}Nm\overline{v}^2$$

$$\overline{KE} = \frac{1}{2}m\overline{v}^2 = \frac{3}{2}kT$$

$$v_{rms} = \sqrt{\frac{3kT}{m}}$$

v_{rms} = ave speed of one particle, k = 1.38×10^{-23} J/K, T = temperature (K), m = mass of one particle (kg)

Not all the ____________ go the same ____________

- Higher ____________, means higher ____________

An apartment has a living room whose dimensions are 2.5 m × 4.0 m × 5.0 m. Assume that the air in the room is composed of 79% nitrogen (N_2) and 21% (O_2). At a temperature of 22 °C and a pressure of 1.01×10^5 Pa, what is the mass of the air?

Physics 06-02 Ideal Gas Law and Kinetic Theory **Name: ________________________**

Helium, a monatomic gas, fills a 0.010-m³ container. The pressure of the gas is 6.2×10^5 Pa. If there are 3 mol of gas, what is the temperature of the gas?

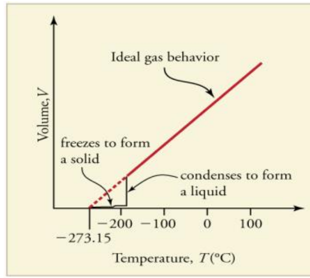
What is the v_{rms}?

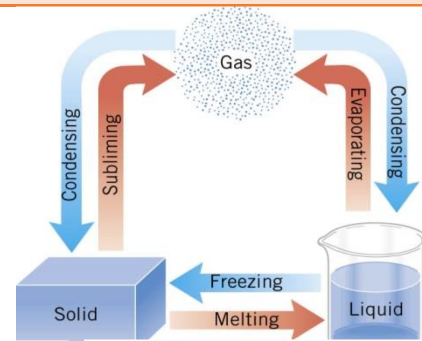
Homework

1. Find out the human population of Earth. Is there a mole of people inhabiting Earth? If the average mass of a person is 60 kg, calculate the mass of a mole of people. How does the mass of a mole of people compare with the mass of Earth?
2. (a) Which, if either, contains a greater number of molecules, a mole of hydrogen (H_2) or a mole of oxygen (O_2)? (b) Which one has more mass? Give reasons for your answers.
3. A tightly sealed house has a large ceiling fan that blows air out of the house and into the attic. This fan is turned on, and the owners forget to open any windows or doors. What happens to the air pressure in the house after the fan has been on for a while, and does it become easier or harder for the fan to do its job? Explain.
4. Above the liquid in a can of hair spray is a gas at a relatively high pressure. The label on the can includes the warning "Do not store at high temperatures." Use the ideal gas law and explain why the warning is given.
5. The gauge pressure in your car tires is 2.50×10^5 N/m² at a temperature of 35.0°C when you drive it onto a ferry boat to Alaska. What is their gauge pressure later, when their temperature has dropped to −40.0°C? (OpenStax 13.22) **1.62 atm**
6. Large helium-filled balloons are used to lift scientific equipment to high altitudes. (a) What is the pressure inside such a balloon if it starts out at sea level with a temperature of 10.0°C and a pressure of 1 atm, and rises to an altitude where its volume is twenty times the original volume and its temperature is −50.0°C? (b) What is the gauge pressure? (Assume atmospheric pressure is constant.) (OpenStax 13.25) **0.0394 atm, −0.961 atm**
7. Calculate the number of moles in the 2.00-L volume of air in the lungs of the average person. Note that the air is at 37.0°C (body temperature). (OpenStax 13.28) $\mathbf{7.86 \times 10^{-2}}$ **mol**
8. An airplane passenger has 100 cm³ of air in his stomach just before the plane takes off from a sea-level airport. What volume will the air have at cruising altitude if cabin pressure drops to 7.50×10^4 N/m²? (OpenStax 13.29) **135 cm³**
9. An expensive vacuum system can achieve a pressure as low as 1.00×10^{-7} N/m² at 20°C . How many atoms are there in a cubic centimeter at this pressure and temperature? (OpenStax 13.31) $\mathbf{2.47 \times 10^{7}}$ **atoms**
10. (a) In the deep space between galaxies, the density of atoms is as low as 10^6 atoms/m³, and the temperature is a frigid 2.7 K. What is the pressure? (b) What volume (in m³) is occupied by 1 mol of gas? (c) If this volume is a cube, what is the length of its sides in kilometers? (OpenStax 13.38) $\mathbf{3.7 \times 10^{-17}}$ **Pa,** $\mathbf{6.0 \times 10^{17}}$ **m³, 840 km**
11. Some incandescent light bulbs are filled with argon gas. What is v_{rms} for argon atoms near the filament, assuming their temperature is 2500 K? (OpenStax 13.39) $\mathbf{1.25 \times 10^{3}}$ **m/s**
12. Average atomic and molecular speeds (v_{rms}) are large, even at low temperatures. What is v_{rms} for helium atoms at 5.00 K, just one degree above helium's liquefaction temperature? (OpenStax 13.40) **176 m/s**
13. (a) What is the average kinetic energy in joules of hydrogen atoms on the 5500°C surface of the Sun? (b) What is the average kinetic energy of helium atoms in a region of the solar corona where the temperature is 6.00×10^5 K ? (OpenStax 13.41) $\mathbf{1.20 \times 10^{-19}}$ **J,** $\mathbf{1.24 \times 10^{-17} J}$
14. The escape velocity of any object from Earth is 11.2 km/s. (a) Express this speed in m/s and km/h. (b) At what temperature would oxygen molecules (molecular mass is equal to 32.0 g/mol) have an average velocity v_{rms} equal to Earth's escape velocity of 11.1 km/s? (OpenStax 13.42) **40320 km/h,** $\mathbf{1.58 \times 10^{5}}$ **K**
15. Much of the gas near the Sun is atomic hydrogen. Its temperature would have to be 1.5×10^7 K for the average velocity v_{rms} to equal the escape velocity from the Sun. What is that velocity? (OpenStax 13.47) $\mathbf{6.09 \times 10^{5}}$ **m/s**

Physics 06-03 Phase Changes and Humidity   Name: ____________________

Phase Changes





Constant Pressure

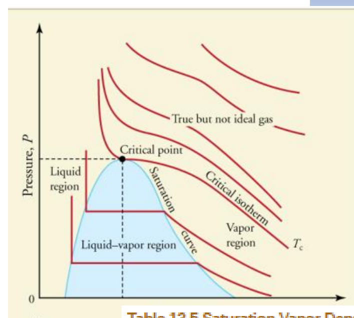
- ________ temps gases have ________ behavior
- ________, volume drops and forms ________
- Colder yet, ________ drops and forms ________

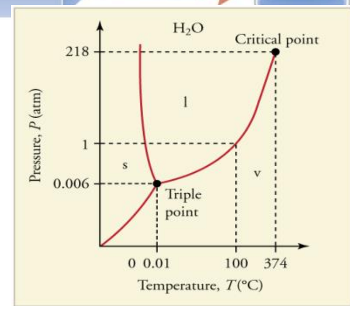
Constant Temperature (________diagram)

- Critical Point - ________ above which ________ cannot exist
- ________ pressure needed for ________

Constant Volume (phase diagram)

- Critical point - Above this temp, no ________
- Triple point - All 3 phases ________
- Lines - 2 phases ________





Humidity

Vapor Pressure

- The pressure at which a gas ________ with its ________ or ________ phase.
- ________ molecules break away from liquid or solid to form ________

Partial Pressure

- The ________ a gas would create if there were ________ gases present.

Total Pressure

- ________ of all ________ pressures of all gases present

Relative Humidity

- How much ________ vapor is in air
  - At 100% humidity, partial ________ of water = ________ pressure
  - If partial pressure < vapor pressure → ________
  - If partial pressure > vapor pressure → ________
- ________ means ________ partial pressure of water
  - Hot air can hold more water
- Saturation Vapor Density - ________ amount of water ________ that air can hold at ________ temp
- Percent Humidity

$$\%\ Relative\ Humidity = \frac{vapor\ density}{saturation\ vapor\ density} \times 100\%$$

Table 13.5 Saturation Vapor Density of Water

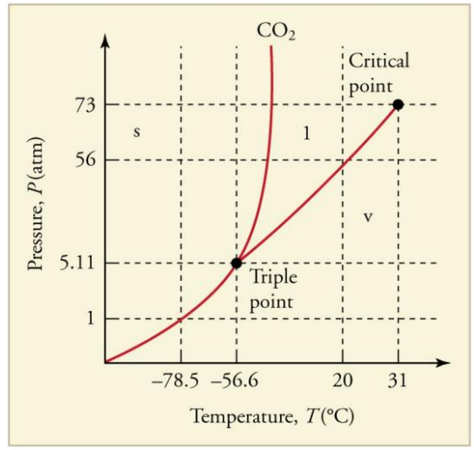
Temperature (°C)	Vapor pressure (Pa)	Saturation vapor density (g/m³)
−50	4.0	0.039
−20	1.04×10^2	0.89
−10	2.60×10^2	2.36
0	6.10×10^2	4.84
5	8.68×10^2	6.80
10	1.19×10^3	9.40
15	1.69×10^3	12.8
20	2.33×10^3	17.2
25	3.17×10^3	23.0
30	4.24×10^3	30.4
37	6.31×10^3	44.0
40	7.34×10^3	51.1
50	1.23×10^4	82.4
60	1.99×10^4	130
70	3.12×10^4	197
80	4.73×10^4	294
90	7.01×10^4	418
95	8.59×10^4	505
100	$\mathbf{1.01 \times 10^5}$	**598**
120	1.99×10^5	1095
150	4.76×10^5	2430
200	1.55×10^6	7090
220	2.32×10^6	10,200

What pressure is necessary to raise the boiling point of water to 150°C? If this was a sealed container, what would the gauge pressure be?

Physics 06-03 Phase Changes and Humidity **Name:** ________________________

Late on an autumn day, the relative humidity is 45.0% and the temperature is 20.0 °C. What will the relative humidity be that evening when the temperature has dropped to 10.0 °C, assuming constant water vapor density?

Homework



1. A camping stove is used to boil water on a mountain. Does it necessarily follow that the same stove can boil water at lower altitudes, such as at sea level? Provide a reason for your answer.
2. Medical instruments are sterilized under the hottest possible temperatures. Explain why they are sterilized in an autoclave, which is a device that is essentially a pressure cooker and heats the instruments in water under a pressure greater than one atmosphere.
3. A bottle of carbonated soda is left outside in subfreezing temperatures, although it remains in the liquid form. When the soda is brought inside and opened, it immediately freezes. Explain why this could happen.
4. What is the vapor pressure of solid carbon dioxide (dry ice) at –78.5°C?
5. Why does a beaker of 40.0°C water placed in a vacuum chamber start to boil as the chamber is evacuated (air is pumped out of the chamber)? At what pressure does the boiling begin? Would food cook any faster in such a beaker?
6. Pressure cookers increase cooking speed by raising the boiling temperature of water above its value at atmospheric pressure. (a) What pressure is necessary to raise the boiling point to 120.0°C? (b) What gauge pressure does this correspond to? (OpenStax 13.51) $\mathbf{1.99 \times 10^5}$ **Pa,** $\mathbf{9.8 \times 10^4}$ **Pa**
7. (a) At what temperature does water boil at an altitude of 1500 m (about 5000 ft) on a day when atmospheric pressure is 8.59×10^4 N/m^2? (b) What about at an altitude of 3000 m (about 10,000 ft) when atmospheric pressure is 7.00×10^4 N/m^2?(OpenStax 13.52) **95°C, 90°C**
8. What is the atmospheric pressure on top of Mt. Everest on a day when water boils there at a temperature of 70.0°C? (OpenStax 13.53) $\mathbf{3.12 \times 10^4}$ **Pa**
9. What is the relative humidity on a 25.0°C day when the air contains 18.0 g/m^3 of water vapor? (OpenStax 13.55) **78.3%**
10. What is the density of water vapor in g/m^3 on a hot dry day in the desert when the temperature is 40.0°C and the relative humidity is 6.00%? (OpenStax 13.56) **3.07 g/m^3**
11. If the relative humidity is 90.0% on a muggy summer morning when the temperature is 20.0°C, what will it be later in the day when the temperature is 30.0°C, assuming the water vapor density remains constant? (OpenStax 13.60) **50.9%**
12. What is the dew point (the temperature at which 100% relative humidity would occur) on a day when relative humidity is 39.0% at a temperature of 20.0°C? (OpenStax 13.63) **4.77°C**
13. Find the partial pressure of water vapor on a day when the weather forecast gives the relative humidity as 56.0% and the temperature as 30.0°C. (Cutnell 12.71) **2400 Pa**

Physics 06-04 Heat and Temperature Change	Name: ________________________

Heat

- Heat is ____________ that flows from a ____________ -temperature object to a ____________ -temperature object because of the ____________ in temperatures
- Unit: ____________ (J), ____________ (cal), kilocalorie (kcal or Cal)

Mechanical Equivalent of Heat

- Since heat is energy, other types of ____________ can make the ____________ effect as heat

$$1\ kcal = 4186\ J$$

- To ____________ the temperature of an object heat is ____________
- The amount of ____________ required is related to
  - ____________ of the object
  - ____________ of temperature change
  - ____________ of the object

$$Q = mc\Delta T$$

- Where Q = heat; c = specific heat capacity (based on material Table 14.1); m = mass; ΔT = change in temperature

Table 14.1 Specific Heats[1] of Various Substances

Substances	Specific heat (c)	
Solids	J/kg·ºC	kcal/kg·ºC[2]
Aluminum	900	0.215
Asbestos	800	0.19
Concrete, granite (average)	840	0.20
Copper	387	0.0924
Glass	840	0.20
Gold	129	0.0308
Human body (average at 37 °C)	3500	0.83
Ice (average, -50°C to 0°C)	2090	0.50
Iron, steel	452	0.108
Lead	128	0.0305
Silver	235	0.0562
Wood	1700	0.4
Liquids		
Benzene	1740	0.415
Ethanol	2450	0.586
Glycerin	2410	0.576
Mercury	139	0.0333
Water (15.0 °C)	4186	1.000
Gases [3]		
Air (dry)	721 (1015)	0.172 (0.242)
Ammonia	1670 (2190)	0.399 (0.523)
Carbon dioxide	638 (833)	0.152 (0.199)
Nitrogen	739 (1040)	0.177 (0.248)
Oxygen	651 (913)	0.156 (0.218)
Steam (100°C)	1520 (2020)	0.363 (0.482)

A pot of 10 kg of 15-°C water is put on a stove and brought to a boil. How much heat was needed?

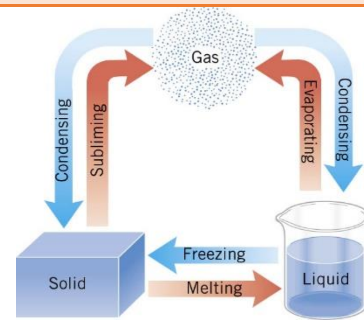
What is the increase in temperature of a 50 g nail hit by a hammer with force of 500N? The length of the nail is .06m its specific heat capacity is 450 J/kg°C.

Physics 06-04 Heat and Temperature Change	**Name: ________________________**
Homework	

1. Two identical mugs contain hot chocolate from the same pot. One mug is full, while the other is only one-quarter full. Sitting on the kitchen table, which mug stays warmer longer? Explain.
2. How is heat transfer related to temperature?
3. When heat transfers into a system, is the energy stored as heat? Explain briefly.
4. What three factors affect the heat transfer that is necessary to change an object's temperature?
5. On a hot day, the temperature of an 80,000-L swimming pool increases by 1.50°C. What is the net heat transfer during this heating? Ignore any complications, such as loss of water by evaporation. (OpenStax 14.1) $\mathbf{5.02 \times 10^8}$ **J**
6. To sterilize a 50.0-g glass baby bottle, we must raise its temperature from 22.0°C to 95.0°C. How much heat transfer is required? (OpenStax 14.3) $\mathbf{3.07 \times 10^3}$ **J**
7. The same heat transfer into identical masses of different substances produces different temperature changes. Calculate the final temperature when 1.00 kcal of heat transfers into 1.00 kg of the following, originally at 20.0°C: (a) water; (b) concrete; (c) steel; and (d) mercury. (OpenStax 14.4) **21.0 °C, 25.0 °C, 29.3 °C, 50.0 °C**
8. Rubbing your hands together warms them by converting work into thermal energy. If a woman rubs her hands back and forth for a total of 20 rubs, at a distance of 7.50 cm per rub, and with an average frictional force of 40.0 N, what is the temperature increase? The mass of tissues warmed is only 0.100 kg, mostly in the palms and fingers. (OpenStax 14.5) **0.171 °C**
9. A 0.250-kg block of a pure material is heated from 20.0°C to 65.0°C by the addition of 4.35 kJ of energy. Calculate its specific heat and identify the substance of which it is most likely composed. (OpenStax 14.6) **0.0924 kcal/kg·°C**
10. The number of kilocalories in food is determined by calorimetry techniques in which the food is burned and the amount of heat transfer is measured. How many kilocalories per gram are there in a 5.00-g peanut if the energy from burning it is transferred to 0.500 kg of water held in a 0.100-kg aluminum cup, causing a 54.9°C temperature increase? (OpenStax 14.8)**5.73 kcal/g**
11. Even when shut down after a period of normal use, a large commercial nuclear reactor transfers thermal energy at the rate of 150 MW by the radioactive decay of fission products. This heat transfer causes a rapid increase in temperature if the cooling system fails (1 watt = 1 joule/second or 1 W = 1 J/s and 1 MW = 1 megawatt). (a) Calculate the rate of temperature increase in degrees Celsius per second (°C/s) if the mass of the reactor core is 1.60×10^5 kg and it has an average specific heat of 0.3349 kJ/kg·°C. (b) How long would it take to obtain a temperature increase of 2000°C, which could cause some metals holding the radioactive materials to melt? (The initial rate of temperature increase would be greater than that calculated here because the heat transfer is concentrated in a smaller mass. Later, however, the temperature increase would slow down because the 5×10^5-kg steel containment vessel would also begin to heat up.) (OpenStax 14.10) **2.80 °C/s, 11.9 min**
12. Blood can carry excess energy from the interior to the surface of the body, where the energy is dispersed in a number of ways. While a person is exercising, 0.6 kg of blood flows to the surface of the body and releases 2000 J of energy. The blood arriving at the surface has the temperature of the body interior, 37.0°C. Assuming that blood has the same specific heat capacity as water, determine the temperature of the blood that leaves the surface and returns to the interior. (Cutnell 12.39) **36.2 °C**
13. If the price of electrical energy is $0.10 per kilowatt·hour, what is the cost of using electrical energy to heat the water in a swimming pool (12.0 m × 9.00 m × 1.5 m) from 15 to 27 °C? (Cutnell 12.41) **$230**

Physics 06-05 Phase Change and Latent Heat	***Name: ____________________***
Phase Change	

- ____________ is required to (or released by) changing the ____________ bonds in ____________ of matter
- Heat ____________ always ____________ the ________________ of a material
- Phases of matter
    - Solid
    - Liquid
    - Gas
- Top arrows ____________ energy
- Bottom arrows ____________ energy



When you cook pasta (or anything that requires boiling), is it better to have a vigorous boil or to turn down the heat to produce barely boiling water?

Latent heat

- The amount of ____________ per ____________ required to change ____________

$$Q = mL$$

- Q = heat required; m = mass; L = latent heat

Latent heat of fusion (L_f)

- Refers to change between ____________ and ____________

Latent heat of vaporization (L_v)

- Refers to change between ____________ and ____________

Latent heat of sublimation (L_s)

- Refers to change between ____________ and ____________

Table 14.2 Heats of Fusion and Vaporization [4]

		L_f			L_v	
Substance	**Melting point (ºC)**	**kJ/kg**	**kcal/kg**	**Boiling point (°C)**	**kJ/kg**	**kcal/kg**
Helium	−269.7	5.23	1.25	−268.9	20.9	4.99
Hydrogen	−259.3	58.6	14.0	−252.9	452	108
Nitrogen	−210.0	25.5	6.09	−195.8	201	48.0
Oxygen	−218.8	13.8	3.30	−183.0	213	50.9
Ethanol	−114	104	24.9	78.3	854	204
Ammonia	−75		108	−33.4	1370	327
Mercury	−38.9	11.8	2.82	357	272	65.0
Water	0.00	334	79.8	100.0	2256[5]	539[6]
Sulfur	119	38.1	9.10	444.6	326	77.9
Lead	327	24.5	5.85	1750	871	208
Antimony	631	165	39.4	1440	561	134
Aluminum	660	380	90	2450	11400	2720
Silver	961	88.3	21.1	2193	2336	558
Gold	1063	64.5	15.4	2660	1578	377
Copper	1083	134	32.0	2595	5069	1211
Uranium	1133	84	20	3900	1900	454
Tungsten	3410	184	44	5900	4810	1150

You have a glass of 1-kg warm water (25°C). To make it cold you put in some ice cubes (-5°C). After an equilibrium temperature is reached, there is a little ice left. What is the minimum mass of the ice cubes? (Assume no heat is lost to the environment.)

Physics 06-05 Phase Change and Latent Heat	***Name: _______________________***
Homework	

1. To help lower the high temperature of a sick patient, an alcohol rub is sometimes used. Isopropyl alcohol is rubbed over the patient's back, arms, legs, etc., and allowed to evaporate. Why does the procedure work?
2. Fruit blossoms are permanently damaged when the temperature drops below about -4°C (a "hard freeze"). Orchard owners sometimes spray a film of water over the blossoms to protect the when a hard freeze is expected. From the point of view of phase changes, give a reason for the protection.
3. Heat transfer can cause temperature and phase changes. What else can cause these changes?
4. How does the latent heat of fusion of water help slow the decrease of air temperatures, perhaps preventing temperatures from falling significantly below 0°C, in the vicinity of large bodies of water?
5. What is the temperature of ice right after it is formed by freezing water?
6. If you place 0°C ice into 0°C water in an insulated container, what will happen? Will some ice melt, will more water freeze, or will neither take place?
7. In very humid climates where there are numerous bodies of water, such as in Florida, it is unusual for temperatures to rise above about 35°C (95°F). In deserts, however, temperatures can rise far above this. Explain how the evaporation of water helps limit high temperatures in humid climates.
8. How much heat transfer (in kilocalories) is required to thaw a 0.450-kg package of frozen vegetables originally at 0°C if their heat of fusion is the same as that of water? (OpenStax 14.11) **35.9 kcal**
9. A bag containing 0°C ice is much more effective in absorbing energy than one containing the same amount of 0°C water. (a) How much heat transfer is necessary to raise the temperature of 0.800 kg of water from 0°C to 30.0°C? (b) How much heat transfer is required to first melt 0.800 kg of 0°C ice and then raise its temperature? (c) Explain how your answer supports the contention that the ice is more effective. (OpenStax 14.12) $\mathbf{1.00 \times 10^{5}}$ **J,** $\mathbf{3.68 \times 10^{5}}$ **J**
10. (a) How much heat transfer is required to raise the temperature of a 0.750-kg aluminum pot containing 2.50 kg of water from 30.0°C to the boiling point and then boil away 0.750 kg of water? (b) How long does this take if the rate of heat transfer is 500 W? (OpenStax 14.13) **4940 s**
11. In 1986, a gargantuan iceberg broke away from the Ross Ice Shelf in Antarctica. It was approximately a rectangle 160 km long, 40.0 km wide, and 250 m thick. (a) What is the mass of this iceberg, given that the density of ice is 917 kg/m^3? (b) How much heat transfer (in joules) is needed to melt it? (c) How many years would it take sunlight alone to melt ice this thick, if the ice absorbs an average of 100 W/m^2, 12.00 h per day? (OpenStax 14.18) $\mathbf{1.47 \times 10^{15}}$ **kg,** $\mathbf{4.90 \times 10^{20}}$ **J, 48.5 y**
12. The energy released from condensation in thunderstorms can be very large. Calculate the energy released into the atmosphere for a small storm of radius 1 km, assuming that 1.0 cm of rain is precipitated uniformly over this area. (OpenStax 14.21) $\mathbf{7 \times 10^{13}}$ **J**
13. To help prevent frost damage, 4.00 kg of onto a fruit tree. 0°C water is sprayed. (a) How much heat transfer occurs as the water freezes? (b) How much would the temperature of the 200-kg tree decrease if this amount of heat transferred from the tree? Take the specific heat to be 3.35 kJ/kg·°C, and assume that no phase change occurs. (OpenStax 14.22) **319 kcal, 2.00 °C**
14. A woman finds the front windshield of her car covered with ice at −12 °C. The ice has a thickness of 4.50×10^{-4} m, and the windshield has an area of 1.25 m^2. The density of ice is 917 kg/m^3. How much heat is required to melt the ice? (Cutnell 12.57) $\mathbf{1.85 \times 10^{5}}$ **J**

06-06 Conduction   *Name: ____________________*

Conduction

- Process where heat is ______________ through a ______________ without any ______________ of the material
- The objects are in ______________ with each other
- Often happens when energetic ______________ molecules bump into less energetic ______________ molecules
- When this happens energy is ______________

Thermal conductors

- Materials that ______________ heat well
- ______________

Thermal insulators

- Materials that conduct heat ______________
- ______________, ______________, ______________

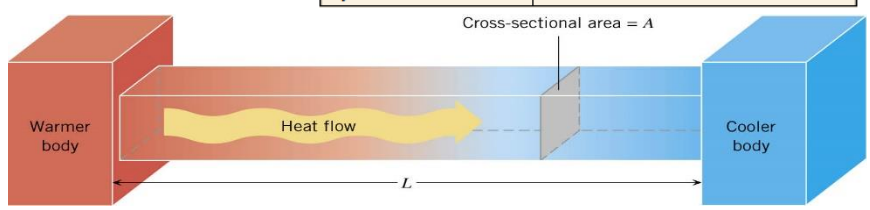
Conduction of Heat through a Bar

$$\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$$

- k = thermal conductivity (Table 14.3), A = cross-sectional area, $T_2 - T_1$ = difference in temperature between ends, t = time of heat transfer, d = length of bar

Table 14.3 Thermal Conductivities of Common Substances[7]

Substance	Thermal conductivity k (J/s·m·°C)
Silver	420
Copper	390
Gold	318
Aluminum	220
Steel iron	80
Steel (stainless)	14
Ice	2.2
Glass (average)	0.84
Concrete brick	0.84
Water	0.6
Fatty tissue (without blood)	0.2
Asbestos	0.16
Plasterboard	0.16
Wood	0.08–0.16
Snow (dry)	0.10
Cork	0.042
Glass wool	0.042
Wool	0.04
Down feathers	0.025
Air	0.023
Styrofoam	0.010

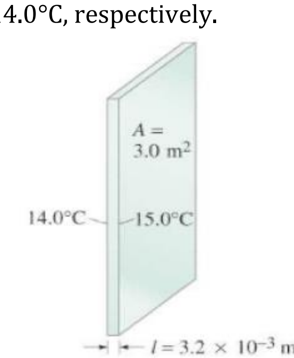


There are two ways to create good insulators

- Small k and big d
- Ratio d/k called ______________
    - ______________ the R factor, ______________ insulator
- Other insulators like ______________ and ______________ work by ______________ air in small spaces where convection currents cannot arise

How much heat is transferred through the Styrofoam insulation the walls of a refrigerator in an hour? The total area of the walls are about 4 m^2 and the Styrofoam is 30mm thick. The temperature inside is 5°C and the room is 25°C.

A major source of heat loss from a house is through the windows. Calculate the rate of heat flow through a glass window 2.0 m × 1.5 m in area and 3.2 mm thick, if the temperatures at the inner and outer surfaces are 15.0°C and 14.0°C, respectively.



06-06 Conduction	***Name: ______________________***
Homework	

1. What are the main methods of heat transfer from the hot core of Earth to its surface? From Earth's surface to outer space?
2. Grandma says that it is quicker to bake a potato if you put a nail into it. In fact, she is right. Justify her baking technique in terms of one of the three processes of heat transfer.
3. Concrete walls often contain steel reinforcement bars. Does the steel enhance or degrade the insulating value of the concrete? Explain.
4. (a) Calculate the rate of heat conduction through house walls that are 13.0 cm thick and that have an average thermal conductivity twice that of glass wool. Assume there are no windows or doors. The surface area of the walls is 120 m^2 and their inside surface is at 18.0°C, while their outside surface is at 5.00°C. (b) How many 1-kW room heaters would be needed to balance the heat transfer due to conduction? (OpenStax 14.30) $\mathbf{1.01 \times 10^3}$ **W, 1**
5. The rate of heat conduction out of a window on a winter day is rapid enough to chill the air next to it. To see just how rapidly the windows transfer heat by conduction, calculate the rate of conduction in watts through a 3.00-m^2 window that is 0.635 cm thick (1/4 in) if the temperatures of the inner and outer surfaces are 5.00°C and −10.0°C, respectively. This rapid rate will not be maintained—the inner surface will cool, and even result in frost formation. (OpenStax 14.31) $\mathbf{6.0 \times 10^3}$ **W**
6. Calculate the rate of heat conduction out of the human body, assuming that the core internal temperature is 37.0°C, the skin temperature is 34.0°C, the thickness of the tissues between averages 1.00 cm , and the surface area is 1.40 m^2. (OpenStax 14.32) **84.0 W**
7. Suppose you stand with one foot on ceramic flooring and one foot on a wool carpet, making contact over an area of 80.0 cm^2 with each foot. Both the ceramic and the carpet are 2.00 cm thick and are 10.0°C on their bottom sides. At what rate must heat transfer occur from each foot to keep the top of the ceramic and carpet at 33.0°C? (OpenStax 14.33) **0.368 W, 7.73 W**
8. (a) What is the rate of heat conduction through the 3.00-cm-thick fur of a large animal having a 1.40-m^2 surface area? Assume that the animal's skin temperature is 32.0°C, that the air temperature is −5.00°C, and that fur has the same thermal conductivity as air. (b) What food intake will the animal need in one day to replace this heat transfer? (OpenStax 14.36) **39.7 W, 820 kcal**
9. A walrus transfers energy by conduction through its blubber at the rate of 150 W when immersed in −1.00°C water. The walrus's internal core temperature is 37.0°C, and it has a surface area of 2.00 m^2. What is the average thickness of its blubber, which has the conductivity of fatty tissues without blood? (OpenStax 14.37) **10.1 cm**
10. A person's body is covered with 1.6 m^2 of wool clothing. The thickness of the wool is 2.0×10^{-3} m. The temperature at the outside surface of the wool is 11 °C, and the skin temperature is 36 °C. How much heat per second does the person lose due to conduction? (Cutnell 13.1) **800 J/s**
11. In an electrically heated home, the temperature of the ground in contact with a concrete basement wall is 12.8 °C. The temperature at the inside surface of the wall is 20.0°C. The wall is 0.10 m thick and has an area of 9.0 m^2. Assume that one kilowatt · hour of electrical energy costs \$0.10. How many hours are required for one dollar's worth of energy to be conducted through the wall? (Cutnell 13.3) **18 h**

Physics 06-07 Convection and Radiation *Name:* ____________________

Convection

- Flow of heat due to the _______________ of matter
- Artificial
  - _______________ system pumps blood
  - _______________ pumps antifreeze
- Natural
  - Difference in _______________ of fluids with different temperatures
  - Warm air rises, cold air falls

When you are working out, your sweat evaporates to cool you. How much sweat must evaporate to lower the body temperature of a 80-kg man by 1°C?

One winter day, the climate control system of a large university classroom building malfunctions. As a result, 250 m^3 of excess cold air is brought in each minute. At what rate in kilowatts must heat transfer occur to warm this air by 10.0°C (that is, to bring the air to room temperature)?

Wind chill

- Air feels colder when wind is blowing because heat is removed by _______________ as well as _______________.

At what temperature does still air cause the same chill factor as 2°C air moving at 5 m/s?

Table 14.4 Wind-Chill Factors

Moving air temperature	Wind speed (m/s)				
(°C)	2	5	10	15	20
5	3	−1	−8	−10	−12
2	0	−7	−12	−16	−18
0	−2	−9	−15	−18	−20
−5	−7	−15	−22	−26	−29
−10	−12	−21	−29	−34	−36
−20	−23	−34	−44	−50	−52
−10	−12	−21	−29	−34	−36
−20	−23	−34	−44	−50	−52
−40	−44	−59	−73	−82	−84

Radiation

- Transfer of energy via ______________________ waves (radio waves, microwaves, x-rays, infrared, and visible light)
- All bodies (objects) _______________ emit radiation
  - Bodies like ice cubes emit _______________ radiation
  - Warm bodies, like human bodies, emit _______________ radiation
  - When the temperature of a body reaches _______________, it starts to emit visible dull red light
  - When the temperature of a body reaches _______________, it emits white-hot light
- Different objects react differently to radiation
  - Black box _______________ most of radiation
  - Silver box _______________ little radiation
    - The rest of the radiation is reflected
- Blackbody is an object that _______________ _______________ radiation that hits it
  - All objects _______________ and _______________ radiation continually—Good absorbers are also good emitters

Stefan-Boltzmann Law of Radiation

$$\frac{Q}{t} = \sigma e A T^4$$

- $\frac{Q}{t}$ = rate of heat transfer, σ = 5.67x10^{-8} J/(s m^2 K^4), e = emissivity (% of radiation emitted as compared to a perfect emitter), A = surface area, T = temperature in Kelvin

Physics 06-07 Convection and Radiation *Name: ______________________*

Because heat is both ______________ and ______________ at the same time, the ______________ of heat transfer by radiation is

$$\frac{Q}{t} = \sigma e A (T_2^4 - T_1^4)$$

- T_1 = temperature of object, T_2 = temperature of surrounding, e = emissivity of object, A = surface are of object

Find the rate that heat is radiated by the sun if the surface temperature is 6000K and emissivity = 1.

Find rate that heat is radiated from a bald head if we estimate that it is a sphere with radius 120 mm and emissivity of 0.97. (Body temperature is 37.0°C and the surrounding room is at 20°C)

Homework

1. One often hears about heat transfer by convection in gases and liquids, but not in solids. Why?
2. One way that heat is transferred from place to place inside the human body is by the flow of blood. Which one of the three heat transfer processes best describes this action of the blood? Justify your answer.
3. A pot of water is being heated on an electric stove. The diameter of the pot is smaller than the diameter of the heating element on which the pot rests. The exposed outer edges of the heating element are glowing cherry red. When you lift the pot, you see that the part of the heating element beneath it is not glowing cherry red, indicating that it is cooler than the outer edges. Why are the outer edges hotter?
4. If you were stranded in the mountains in cold weather, it would help to minimize energy losses from your body by curling up into the tightest ball possible. Which of the factors in Stefan-Boltzmann Law of Radiation are you using to the best advantage by curling into a ball? Why?
5. Why are cloudy nights generally warmer than clear ones?
6. Why are thermometers that are used in weather stations shielded from the sunshine? What does a thermometer measure if it is shielded from the sunshine and also if it is not?
7. At what wind speed does −10°C air cause the same chill factor as still air at −29°C? (OpenStax 14.45) **10 m/s**
8. The "steam" above a freshly made cup of instant coffee is really water vapor droplets condensing after evaporating from the hot coffee. What is the final temperature of 250 g of hot coffee initially at 90.0°C if 2.00 g evaporates from it? The coffee is in a Styrofoam cup, so other methods of heat transfer can be neglected. (OpenStax 14.47) **85.7°C**
9. (a) How many kilograms of water must evaporate from a 60.0-kg woman to lower her body temperature by 0.750°C? (b) Is this a reasonable amount of water to evaporate in the form of perspiration, assuming the relative humidity of the surrounding air is low? (OpenStax 14.48) $\mathbf{6.44 \times 10^{-2}}$ **kg, Yes**
10. The Kilauea volcano in Hawaii is the world's most active, disgorging about 5×10^5 m^3 of 1200°C lava per day. What is the rate of heat transfer out of Earth by convection if this lava has a density of 2700 kg/m^3 and eventually cools to 30°C? Assume that the specific heat of lava is the same as that of granite. (OpenStax 14.51) $\mathbf{2 \times 10^4}$ **MW**
11. During heavy exercise, the body pumps 2.00 L of blood per minute to the surface, where it is cooled by 2.00°C. What is the rate of heat transfer from this forced convection alone, assuming blood has the same specific heat as water and its density is 1050 kg/m^3? (OpenStax 14.52) **293 W**
12. At what net rate does heat radiate from a 275-m^2 black roof on a night when the roof's temperature is 30.0°C and the surrounding temperature is 15.0°C? The emissivity of the roof is 0.900. (OpenStax 14.55) **−21.7 kW**
13. (a) Cherry-red embers in a fireplace are at 850°C and have an exposed area of 0.200 m^2 and an emissivity of 0.980. The surrounding room has a temperature of 18.0°C. If 50% of the radiant energy enters the room, what is the net rate of radiant heat transfer in kilowatts? (b) Does your answer support the contention that most of the heat transfer into a room by a fireplace comes from infrared radiation? (OpenStax 14.56) **−8.80 kW, yes**
14. Find the net rate of heat transfer by radiation from a skier standing in the shade, given the following. She is completely clothed in white (head to foot, including a ski mask), the clothes have an emissivity of 0.200 and a surface temperature of 10.0°C, the surroundings are at −15.0°C , and her surface area is 1.60 m^2. (OpenStax 14.59) **−36.0 W**
15. The Sun radiates like a perfect black body with an emissivity of exactly 1. (a) Calculate the surface temperature of the Sun, given that it is a sphere with a 7.00×10^8-m radius that radiates 3.80×10^{26} W into 3-K space. (b) How much power does the Sun radiate per square meter of its surface? (c) How much power in watts per square meter is that value at the distance of Earth, 1.50×10^{11} m away? (This number is called the solar constant.) (OpenStax 14.62) $\mathbf{5.74 \times 10^3}$ **K,** $\mathbf{6.17 \times 10^7}$ **W/m²,** $\mathbf{1.34 \times 10^3}$ **W/m²**

Physics 06-08 The 1st Law of Thermodynamics and Simple Processes Name:________________________

Thermodynamics

- The study of laws of heat ______________ and its relationship to ______________

Systems have ______________ energy due to the ______________ and ______________ of the ______________ in it

- Heat can be ______________ by the system
- Because of conservation of energy this changes the ______________ energy of the system
- Heat is ______________ when system ______________ heat
- Heat is ______________ when system ______________ heat

Work can also change ______________ energy of a system

- Work is ______________ when it is done ______________ the system
- Work is ______________ when it is done ______________ the system

1st Law of Thermodynamics

$$\Delta U = Q - W$$

- U = internal energy, Q = heat (positive when system gains Q), W = work (positive when system does W)

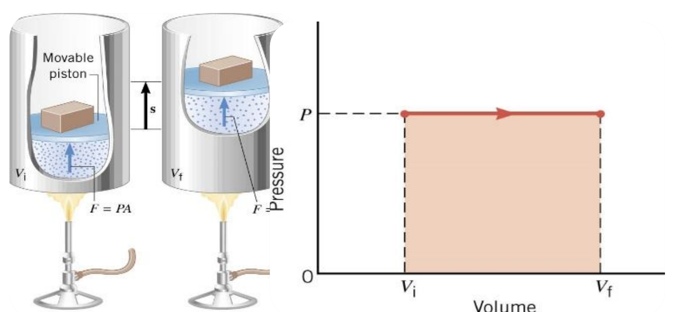
$$\text{For gasses } U = \frac{3}{2}NkT = \frac{3}{2}PV$$

While working on an assignment, Frank does 10000 J of work. In the process, his internal energy decreases by 20000 J. Find W, ΔU, and Q.

Four thermal processes

Each is quasi-static → ______________ enough that ______________ temperature and pressure

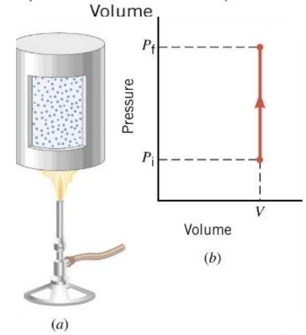
Isobaric



- Constant ______________
- Frictionless piston where the pressure is determined by the weight of the piston (doesn't change)
- As the gas is heated, it expands and pushes the piston up

$$W = P\Delta V = P(V_f - V_i)$$
$$\Delta U = Q - P\Delta V$$

Isochoric



- Constant ______________
- Since no change in volume no work is done

$$\Delta U = Q$$

Isothermal

- Constant ______________
- Usually temperature of a gas decreases as it (PV=nRT) expands, so thermal energy is transferred into the gas from the environment

$$Q = W$$
$$\Delta U = 0$$

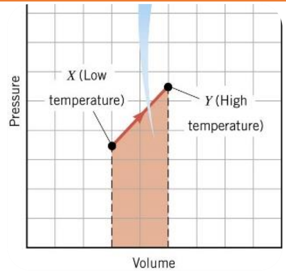
Adiabatic

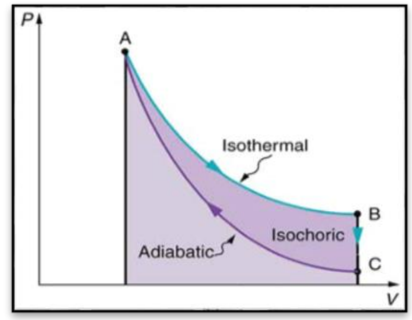
- No heat ______________

$$\Delta U = -W$$

Physics 06-08 The 1st Law of Thermodynamics and Simple Processes *Name:*________________________

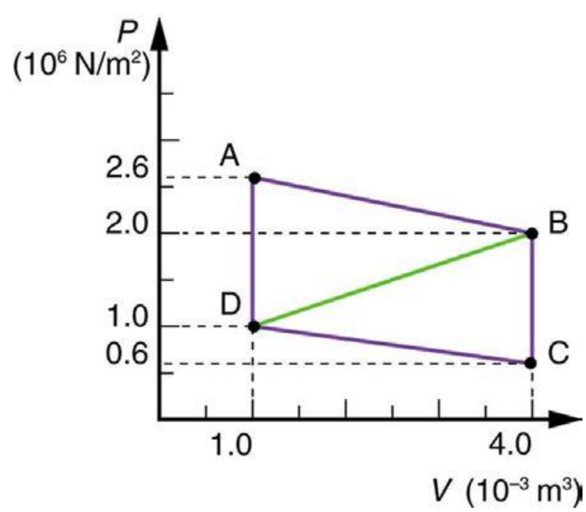
- The area under a Pressure-Volume graph is the ______________
- If the process goes in a ______________, then the work done is the area ______________ the loop on a PV graph
- Since the work can be ______________ or ______________, the processes can go ______________ direction
- In theory it can be ______________ reversed (return to previous state)
- There is always ______________ so there is ______________ completely reversible process





Homework

1. (a) Is it possible for the temperature of a substance to rise without heat flowing into it? (b) Does the temperature of a substance necessarily have to change because heat flows into or out of it? In each case, give your reasoning.
2. Suppose you want to heat a gas so that its temperature will be as high as possible. Would you heat it under conditions of constant pressure or constant volume?
3. How do heat transfer and internal energy differ? In particular, which can be stored as such in a system and which cannot?
4. The temperature of a rapidly expanding gas decreases. Explain why in terms of the first law of thermodynamics. (Hint: Consider whether the gas does work and whether heat transfer occurs rapidly into the gas through conduction.)
5. What is the change in internal energy of a car if you put 12.0 gal of gasoline into its tank? The energy content of gasoline is 1.3×10^8 J/gal. All other factors, such as the car's temperature, are constant. (OpenStax 15.1) $\mathbf{1.6 \times 10^9}$ **J**
6. How much heat transfer occurs from a system, if its internal energy decreased by 150 J while it was doing 30.0 J of work? (OpenStax 15.2) **120 J**
7. A system does 1.80×10^8 J of work while 7.50×10^8 J of heat transfer occurs to the environment. What is the change in internal energy of the system assuming no other changes (such as in temperature or by the addition of fuel)? (OpenStax 15.3) $\mathbf{-9.30 \times 10^8}$ **J**
8. What is the change in internal energy of a system which does 4.50×10^5 J of work while 3.00×10^6 J of heat transfer occurs into the system, and 8.00×10^6 J of heat transfer occurs to the environment? (OpenStax 15.4) $\mathbf{-5.45 \times 10^6}$ **J**
9. Suppose a woman does 500 J of work and 9500 J of heat transfer occurs into the environment in the process. (a) What is the decrease in her internal energy, assuming no change in temperature or consumption of food? (That is, there is no other energy transfer.) (b) What is her efficiency? (OpenStax 15.5) $\mathbf{-1.0 \times 10^4}$ **J, 5.00%**
10. A car tire contains 0.0380 m^3 of air at a pressure of 2.20×10^5 N/m^2 (about 32 psi). How much more internal energy does this gas have than the same volume has at zero gauge pressure (which is equivalent to normal atmospheric pressure)? (OpenStax 15.10) $\mathbf{6.77 \times 10^3}$ **J**
11. A helium-filled toy balloon has a gauge pressure of 0.200 atm and a volume of 10.0 L. How much greater is the internal energy of the helium in the balloon than it would be at zero gauge pressure? (OpenStax 15.11) **300 J**
12. A hand-driven tire pump has a piston with a 2.50-cm diameter and a maximum stroke of 30.0 cm. (a) How much work do you do in one stroke if the average gauge pressure is 2.40×10^5 N/m^2 (about 35 psi)? (b) What average force do you exert on the piston, neglecting friction and gravitational force? (OpenStax 15.13) **35.3 J, 118 N**
13. Calculate the net work output of a heat engine following path ABCDA in the figure. (OpenStax 15.14) $\mathbf{4.5 \times 10^3}$ **J**
14. What is the net work output of a heat engine that follows path ABDA in the figure, with a straight line from B to D? Why is the work output less than for path ABCDA? (OpenStax 15.15) $\mathbf{2.4 \times 10^3}$ **J**



Physics 06-09 The 2nd Law of Thermodynamics and Heat Engines Name: ____________________

- Heat ____________________ moves from ______________ temp to ______________

The 2nd Law of Thermodynamics

Heat Engine

- Uses part of the spontaneous heat transfer to do ______________

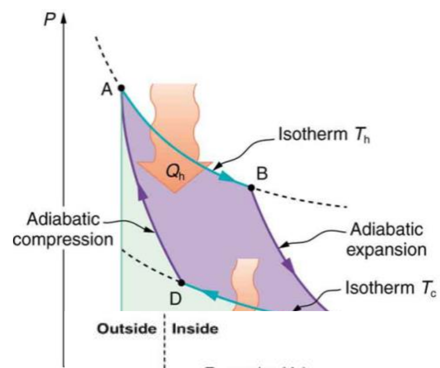
$$W = Q_h - Q_c$$

- Efficiency

$$Eff = \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

- Only 100% efficient if ______________ goes to ______________

The 2nd Law of Thermodynamics (Carnot Engine)

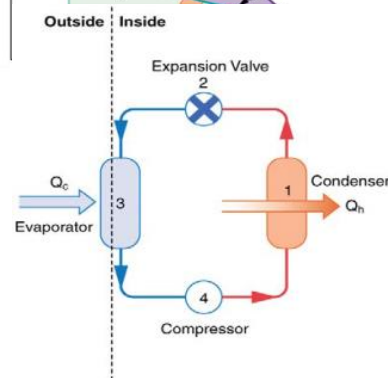


- A Carnot engine operating between two given temperatures has the ______________ possible ______________ of any heat engine operating between these two temperatures.
- Furthermore, all engines employing only ______________ processes have this same ______________ efficiency when operating between the same given temperatures.

$$Eff = 1 - \frac{T_c}{T_h} \qquad \text{(T in Kelvin)}$$

- Carnot Engines use only ______________ processes

Heat Pumps



- Use Carnot cycle to move heat from ______________ temp to ______________

1. Gas at high ______________________ in _________________, so heat goes to room
2. Valve lowers ________________________ turning gas to ______________
3. Heat from ______________ area is used to evaporate ______________
4. Compressor raises ___________________________ of gas

- Coefficient of Performance

$$COP_{hp} = \frac{Q_h}{W} = \frac{1}{Eff}$$

- Low ______________ means high ______________
- For a Carnot engine

$$Eff = 1 - \frac{T_c}{T_h} \qquad \text{(T in Kelvin)}$$

- Heat pumps work best when ______________ temp difference

An automobile engine has an efficiency of 20% and produces an average of 23,000 J of mechanical work per second during operation. (a) How much heat input is required, and (b) how much heat is discharged as waste heat from this engine per second?

Refrigerators and Air Conditioners

- Similar to __________________, but designed to ______________

$$COP_{ref} = \frac{Q_c}{W}$$

$$COP_{ref} = COP_{hp} - 1$$

A heat pump has a coefficient of performance of 3.0 and is rated to do work at 1500 W. (a) How much heat can it add to a room per second? (b) If the heat pump were turned around to act as an air conditioner in the summer, what would you expect its coefficient of performance to be?

Homework

1. Is a temperature difference necessary to operate a heat engine? State why or why not.
2. Can improved engineering and materials be employed in heat engines to reduce heat transfer into the environment? Can they eliminate heat transfer into the environment entirely?
3. Does the second law of thermodynamics alter the conservation of energy principle?
4. Can you cool a kitchen by leaving the refrigerator door open?
5. A certain heat engine does 10.0 kJ of work and 8.50 kJ of heat transfer occurs to the environment in a cyclical process. (a) What was the heat transfer into this engine? (b) What was the engine's efficiency? (OpenStax 15.20) **18.5 kJ, 54.1%**
6. With 2.56×10^6 J of heat transfer into this engine, a given cyclical heat engine can do only 1.50×10^5 J of work. (a) What is the engine's efficiency? (b) How much heat transfer to the environment takes place? (OpenStax 15.21) **5.86%, $\mathbf{2.41 \times 10^6}$ J**
7. (a) What is the work output of a cyclical heat engine having a 22.0% efficiency and 6.00×10^9 J of heat transfer into the engine? (b) How much heat transfer occurs to the environment? (OpenStax 15.22) **$\mathbf{1.32 \times 10^9}$ J, $\mathbf{4.68 \times 10^9}$ J**
8. (a) What is the efficiency of a cyclical heat engine in which 75.0 kJ of heat transfer occurs to the environment for every 95.0 kJ of heat transfer into the engine? (b) How much work does it produce for 100 kJ of heat transfer into the engine? (OpenStax 15.23) **21.1%, 21.1 kJ**
9. The engine of a large ship does 2.00×10^8 J of work with an efficiency of 5.00%. (a) How much heat transfer occurs to the environment? (b) How many barrels of fuel are consumed, if each barrel produces 6.00×10^9 J of heat transfer when burned? (OpenStax 15.24) **$\mathbf{3.80 \times 10^9}$ J, 0.667 barrels**
10. (a) How much heat transfer occurs to the environment by an electrical power station that uses 1.25×10^{14} J of heat transfer into the engine with an efficiency of 42.0%? (b) What is the ratio of heat transfer to the environment to work output? (c) How much work is done? (OpenStax 15.25) **$\mathbf{7.25 \times 10^{13}}$ J, 1.38, $\mathbf{5.25 \times 10^{13}}$ J**
11. Steam locomotives have an efficiency of 17.0% and operate with a hot steam temperature of 425°C . (a) What would the cold reservoir temperature be if this were a Carnot engine? (b) What would the maximum efficiency of this steam engine be if its cold reservoir temperature were 150°C? (OpenStax 15.31) **306°C, 39.4%**
12. What is the coefficient of performance of an ideal heat pump that has heat transfer from a cold temperature of −25.0°C to a hot temperature of 40.0°C? (OpenStax 15.37) **4.82**
13. What is the best coefficient of performance possible for a hypothetical refrigerator that could make liquid nitrogen at −200°C and has heat transfer to the environment at 35.0°C? (OpenStax 15.39) **0.311**
14. Suppose you want to operate an ideal refrigerator with a cold temperature of −10.0°C, and you would like it to have a coefficient of performance of 7.00. What is the hot reservoir temperature for such a refrigerator? (OpenStax 15.43) **27.6°C**

Physics 06-10 Entropy and the 2nd Law of Thermodynamics — Name: ________________________

Entropy

- Amount of _____________ not available for _____________
- Related to amount of _____________

$$\Delta S = \frac{Q}{T}$$

- ΔS = change in entropy, Q = heat transfer, T = temperature (K) [If one object is changing temp, then use average T]

2nd Law of Thermodynamics

The total entropy of a system either _____________ or remains _____________ for any process; it never _____________.

- ______________________ processes always result in
  - _____________ of entropy
  - _____________ energy available to do work

$$W_{unavail} = \Delta S \cdot T_0$$

- Where T_0 is the lowest temperature

1200 J of heat flowing spontaneously through a copper rod from a hot reservoir 650 K to a cold reservoir at 350 K. Determine the amount by which this irreversible process changes the entropy of the universe, assuming that no other changes occur.

Find the change in entropy that results when a 2.3-kg block of ice melts slowly (reversibly) at 273 K (0 °C)

Origins of Life

- If the entropy (or disorderliness) increases, how do evolutionists justify evolution (more orderly)?
  - Need for _____________ since they _____________ by assuming God doesn't exist
  - When energy is put into something, it can _____________ entropy for that thing, but total entropy of universe increases
  - They claim the _____________ gave energy to earth which allowed for ________ to ______________________ appear
  - This would mean __________________ making something that _____________ energy to do ______________________ processes (making less entropy)
  - This has never been duplicated in a lab
- Creationists use a similar idea, only we say __________ gave the _____________ and created highly _____________ creation
  - Ever since then, the creation has been _____________ apart

Statistics of Entropy

- Why do spontaneous processes not decrease entropy?
  - A system can have _____________ parts
  - All those parts have _____________ ways they can be
  - Much more _____________ to get _____________ organized combinations
  - Flip 5 coins
    - Macrostates
      - 5 heads or 4 heads, 1 tail or 3 heads, 2 tails or etc.

- Microstates
  - HHHHH
  - HHHHT, HHHTH, HHTHH, HTHHH, THHHH

Entropy

$$S = k \ln W$$

- $k = 1.38 \times 10^{-23}\,\frac{J}{K}$ Boltzmann's constant, W = number of microstates in system
- Using these statistics, life spontaneously developing is essentially ________________.
- They say that _____________ life exists, it must have _____________
- We say _____________ made it happen

Homework

1. A woman shuts her summer cottage up in September and returns in June. No one has entered the cottage in the meantime. Explain what she is likely to find, in terms of the second law of thermodynamics.
2. Consider a system with a certain energy content, from which we wish to extract as much work as possible. Should the system's entropy be high or low? Is this orderly or disorderly? Structured or uniform? Explain briefly.
3. Does a gas become more orderly when it liquefies? Does its entropy change? If so, does the entropy increase or decrease? Explain your answer.
4. Explain how water's entropy can decrease when it freezes without violating the second law of thermodynamics. Specifically, explain what happens to the entropy of its surroundings.
5. Is a uniform-temperature gas more or less orderly than one with several different temperatures? Which is more structured? In which can heat transfer result in work done without heat transfer from another system?
6. What is the change in entropy in an adiabatic process? Does this imply that adiabatic processes are reversible? Can a process be precisely adiabatic for a macroscopic system?
7. Explain why a building made of bricks has smaller entropy than the same bricks in a disorganized pile. Do this by considering the number of ways that each could be formed (the number of microstates in each macrostate).
8. (a) On a winter day, a certain house loses 5.00×10^8 J of heat to the outside (about 500,000 Btu). What is the total change in entropy due to this heat transfer alone, assuming an average indoor temperature of 21.0 °C and an average outdoor temperature of 5.00 °C? (b) This large change in entropy implies a large amount of energy has become unavailable to do work. Where do we find more energy when such energy is lost to us? (OpenStax 15.47) $\mathbf{9.78 \times 10^4}$ **J/K**
9. On a hot summer day, 4.00×10^6 J of heat transfer into a parked car takes place, increasing its temperature from 35.0 °C to 45.0 °C. What is the increase in entropy of the car due to this heat transfer alone? (OpenStax 15.48) $\mathbf{1.28 \times 10^4}$ **J/K**
10. A hot rock ejected from a volcano's lava fountain cools from 1100 °C to 40.0 °C, and its entropy decreases by 950 J/K. How much heat transfer occurs from the rock? (OpenStax 15.49) $\mathbf{8.01 \times 10^5}$ **J**
11. When 1.60×10^5 J of heat transfer occurs into a meat pie initially at 20.0 °C, its entropy increases by 480 J/K. What is its final temperature? (OpenStax 15.50) **101 °C**
12. The Sun radiates energy at the rate of 3.80×10^{26} W from its 5500 °C surface into dark empty space (a negligible fraction radiates onto Earth and the other planets). The effective temperature of deep space is −270 °C. (a) What is the increase in entropy in one day due to this heat transfer? (b) How much work is made unavailable? (OpenStax 15.51) $\mathbf{1.04 \times 10^{31}}$ **J/K,** $\mathbf{3.28 \times 10^{31}}$ **J**
13. What is the decrease in entropy of 25.0 g of water that condenses on a bathroom mirror at a temperature of 35.0 °C, assuming no change in temperature and given the latent heat of vaporization to be 2450 kJ/kg? (OpenStax 15.53) **−199 J/K**
14. Find the increase in entropy of 1.00 kg of liquid nitrogen that starts at its boiling temperature, boils, and warms to 20.0 °C at constant pressure. (OpenStax 15.54) $\mathbf{3.81 \times 10^3}$ **J/K**
15. Find the change in entropy of the H_2O molecules when (a) three kilograms of ice melts into water at 273 K and (b) three kilograms of water changes into steam at 373 K. (c) On the basis of the answers to parts (a) and (b), discuss which change creates more disorder in the collection of H_2O molecules. (Cutnell 15.71) $\mathbf{3.68 \times 10^3}$ **J/K,** $\mathbf{1.82 \times 10^4}$ **J/K**

Physics

Unit 6: Temperature, Heat, and Thermodynamics

1. *Meanings and concepts of terms like thermal expansion, equilibrium, condensation, evaporation, sublimation, freezing, melting, humidity, heat, calorimeter, convection, conduction, radiation, blackbody radiator, thermodynamics, heat engine, heat pump, Carnot engine, entropy*
2. *The coefficient of linear expansion of aluminum is* 2.3×10^{-6} */C°. A circular hole in an aluminum plate is 10 cm in diameter at 10 °C. What is the diameter of the hole if the temperature of the plate is raised to 100 °C?*
3. *A sample of a monatomic ideal gas is originally at 20 °C. What is the final temperature of the gas if both the pressure and volume are quadrupled?*
4. *Late on an autumn day, the relative humidity is 60% and the temperature in 30 °C. What will the relative humidity be that evening when the temperature has dropped to 10 °C, assuming constant water vapor density?*
5. *A 5-kg lead shot is heated to 200 °C and dropped into an ideal calorimeter containing 10 kg of water initially at 20.0 °C. What is the final equilibrium temperature of the lead shot? The specific heat capacity of lead is 128 J/(kg·C°); and the specific heat of water is 4186 J/(kg·C°).*
6. *What is the minimum amount of energy required to completely melt a 5-kg lead brick which has a starting temperature of 20 °C? The melting point of lead is 328 °C. The specific heat capacity of lead is 128 J/(kg·C°); and its latent heat of fusion is 23200 J/kg.*
7. *A blue supergiant star has a radius of* 5×10^{10} *m. The spherical surface behaves as a blackbody radiator. If the surface temperature is* 5×10^{4} *K, what is the rate at which energy is radiated from the star?*
8. *At what rate is heat lost through a 5 m × 10 m rectangular glass windowpane that is 0.5 cm thick when the inside temperature is 20 °C and the outside temperature -5 °C? The thermal conductivity for glass is 0.80 W/(m·C°).*
9. *A system containing an ideal gas at a constant pressure of* 5×10^{5} *Pa gains 100 J of heat. During the process, the internal energy of the system increases by 500 J. What is the change in volume of the gas?*
10. *An engine is used to lift a 5000 kg truck to a height of 2 m at constant speed. In the lifting process, the engine received* 5×10^{5} *J of heat from the fuel burned in its interior. What is the efficiency of the engine?*
11. *A Carnot heat engine is to be designed with an efficiency of 60%. If the low temperature reservoir is 20 °C, what is the temperature of the "hot" reservoir?*
12. *If the coefficient of performance for a refrigerator is 6 and 1000 J of work are done on the system, how much heat is rejected to the room?*
13. *A 20-kg sample of steam at 100.0 °C condenses to water at 100.0 °C. What is the entropy change of the sample if the heat of vaporization of water is* 2.26×10^{6} *J/kg?*

2. $\alpha = 2.3 \times 10^{-6}/C°, d_1 = 0.10\ m, T_1 = 10\ °C, T_2 = 100\ °C$
$\Delta L = \alpha L \Delta T$
$\Delta L = (2.3 \times 10^{-6}\ /C°)(0.10\ m)(100\ °C - 10\ °C)$
$\Delta L = 2.07 \times 10^{-5}\ m$
$d_2 = 0.10\ m + 2.07 \times 10^{-5}\ m = \mathbf{1.0002 \times 10^{-1}\ m}$

3. $T_1 = 20\ °C = 293.15\ K, P_2 = 4P_1, V_2 = 4V_1$
$PV = nRT$
$\frac{PV}{T} = nR$
since nR is constant
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
$\frac{P_1V_1}{293.15\ K} = \frac{(4P_1)(4V_1)}{T_2}$
$\frac{1}{293.15\ K} = \frac{16}{T_2}$
$T_2 = \mathbf{4690\ K = 4417\ °C}$

4. $\%\ hum_1 = 60\ \%, T_1 = 30\ °C, T_2 = 10\ °C$
$\%\ relative\ humidity = \frac{vapor\ density}{saturation\ vapor\ density} \times 100\%$
$60\ \% = \frac{vapor\ density}{30.4 \frac{g}{m^3}} \times 100\%$
$vapor\ denstiy = 18.24 \frac{g}{m^3}$
$\%\ humid = \frac{18.24 \frac{g}{m^3}}{9.4 \frac{g}{m^3}} \times 100\%$
$\%\ humidity = \mathbf{194}\ \%$
This can't really happen. It started raining and the humidity stayed at 100%.

5. $m_l = 5\ kg, T_l = 200\ °C, m_w = 10\ kg, T_w = 20°C, c_l = 128 \frac{J}{kg \cdot C°}, c_w = 4186 \frac{J}{kg \cdot C°}$
$Q = mc\Delta T$
$-Q_l = Q_w$
$-(5\ kg)\left(128 \frac{J}{kg \cdot C°}\right)(T_f - 200°C) = (10\ kg)\left(4186 \frac{J}{kg \cdot C°}\right)(T_f - 20\ °C)$
$-640 \frac{J}{C°} T_f + 128000\ J = 41860 \frac{J}{C°} T_f - 837200\ J$
$-42500 \frac{J}{C°} T_f = -965200\ J$
$T_f = \mathbf{22.7\ °C}$

6. $m = 5\ kg, T_0 = 20\ °C, T_{melt} = 328\ °C, c = 128 \frac{J}{kg \cdot C°}, L_f = 23200 \frac{J}{kg}$
$Q = mc\Delta T$
$Q = (5\ kg)\left(128 \frac{J}{kg \cdot C°}\right)(328\ °C - 20\ °C)$
$Q = 197120\ J$
$Q_{melt} = mL_f$
$Q_{melt} = (5\ kg)\left(23200 \frac{J}{kg}\right) = 116000\ J$
$Q_{tot} = 197120\ J + 116000\ J = \mathbf{313120\ J}$

7. $r = 5 \times 10^{10} m, T = 5 \times 10^4 K, e = 1$
$\frac{Q}{t} = \sigma e A T^4$
$\frac{Q}{t} = \left(5.67 \times 10^{-8} \frac{J}{s \cdot m^2 \cdot K^4}\right)(1)(4\pi(5 \times 10^{10}\ m)^2)(5 \times 10^4\ K)^4$
$\frac{Q}{t} = \mathbf{1.11 \times 10^{34} \frac{J}{s}}$

8. $A = (5\ m)(10\ m) = 50\ m^2, d = 0.005\ m, T_2 = -5\ °C, T_1 = 20\ °C, k = 0.80 \frac{W}{m \cdot C°}$
$\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$
$\frac{Q}{t} = \frac{\left(0.80 \frac{W}{m \cdot C°}\right)(50\ m^2)(-5\ °C - 20\ °C)}{0.005\ m}$
$\frac{Q}{t} = \mathbf{-200000 \frac{J}{s}}$

9. $P = 5 \times 10^5\ Pa, Q = 100\ J, \Delta U = 500\ J$
$\Delta U = Q - W$
$500\ J = 100\ J - W$
$W = -400\ J$
$W = P\Delta V\ (isobaric\ process)$
$-400\ J = (5 \times 10^5\ Pa)\Delta V$
$\Delta V = \mathbf{-0.0008\ m^3}$

10. $m = 5000\ kg, h = 2\ m, Q = 5 \times 10^5\ J$
$Eff = \frac{W}{Q_h}$
$Eff = \frac{(5000\ kg)\left(9.8 \frac{m}{s^2}\right)(2\ m)}{5 \times 10^5\ J} = \mathbf{0.196}$

11. $Eff_C = 0.60, T_c = 20\ °C = 293.15\ K$
$Eff_C = 1 - \frac{T_c}{T_h}$
$0.60 = 1 - \frac{293.15\ K}{T_h}$
$-0.40 = -\frac{293.15\ K}{T_h}$
$T_h = \frac{-293.15\ K}{-0.40} = \mathbf{732.88\ K = 439.73\ °C}$

12. $COP_{ref} = 6, W = 1000\ J$
$COP_{ref} = \frac{Q_c}{W}$
$6 = \frac{Q_c}{1000\ J}$
$Q_c = \mathbf{6000\ J}$

13. $m = 20\ kg, T = 100\ °C = 373.15\ K, L_v = 2.26 \times 10^6 \frac{J}{kg}$
$\Delta S = \frac{Q}{T}$
$\Delta S = \frac{-(20\ kg)\left(2.26 \times 10^6 \frac{J}{kg}\right)}{373.15\ K} = \mathbf{-121000 \frac{J}{K}}$