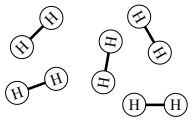
Sample
Physics 3410 Exam 1 Solutions

3 1. **C** Which of the following is an extensive variable?
A) pressure **B)** temperature **C)** volume

3 2. **F** True or false: If an object cools down, then heat must have flowed out of it.

3 3. **C** Which kind of heat can travel through vacuum?
A) conduction **B)** convection **C)** radiation **D)** none of these **E)** all of these

4. Hydrogen gas, containing 2×10^{24} molecules of H_2, has temperature $T = 800\,\text{K}$ and is at pressure $P = 3 \times 10^4\,\text{Pa}$. *All* of its degrees of freedom are active.



3 (a) What volume does the gas occupy?

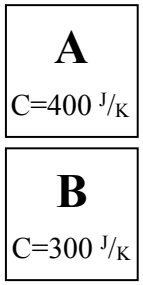
$$PV = NkT \implies V = \frac{NkT}{P} = \frac{(2 \times 10^{24})(1.38 \times 10^{-23})(800)}{3 \times 10^4} = \boxed{0.74\,\text{m}^3}$$

3 (b) What is the internal energy U of the gas?

$$f = 3\,\text{translational} + 2\,\text{rotational} + 2\,\text{vibrational} = 7.$$

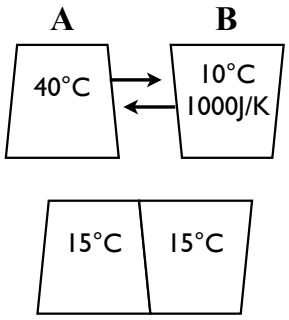
$$U = N\frac{f}{2}kT = (2 \times 10^{24})\frac{7}{2}(1.38 \times 10^{-23})(800) = \boxed{7.7 \times 10^4\,\text{J}}$$

3 5. **A** Block A has heat capacity $C = 400\,\text{J/K}$, and block B has $C = 300\,\text{J/K}$. Both blocks are removed from a $5\,^\circ\text{C}$ refrigerator and placed in a $20\,^\circ\text{C}$ room until they reach room temperature. Which block absorbs more heat from the room?
A) Block A **B)** Block B
C) Both blocks absorb the same amount of heat



$Q = C_V \Delta T$: ΔT is the same so larger C_V means more Q.

6. Block A starts at 40 °C, and block B starts at 10 °C. They are placed in contact with each other, and heat flows between them until the temperature of both is 15 °C. (No heat flows into or out of the environment.)



[3] (a) B Which block has the larger heat capacity?
A) Block A **B)** Block B
C) Both have the same heat capacity

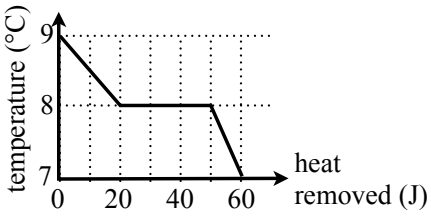
[1] (b) B In which direction does heat flow?
A) into A **B)** into B

[3] (c) B If the heat capacity of block B is $C = 1\,\text{kJ/K}$, how much heat flows between the blocks?
A) 1 kJ **B)** 5 kJ **C)** 10 kJ
D) 15 kJ **E)** 25 kJ **F)** 30 kJ

$$Q = C_V \Delta T = (1\,\text{kJ/K})(15\,^\circ\text{C} - 10\,^\circ\text{C}) = 5\,\text{kJ}$$

[2] 7. C When water vapor condenses to a liquid
A) it absorbs energy from the surroundings **B)** its temperature drops sharply
C) it transfers heat to the surroundings **D)** its temperature rises slightly

[2] 8. A certain liquid starts at 9 °C, and 60 J of heat is slowly removed from it, as shown. Once it reaches 7 °C, it has become a solid. What is the latent heat of freezing of this liquid, in Joules?



30 J

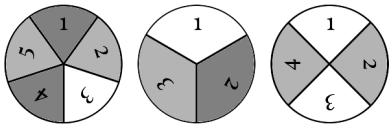
9. A gas shrinks and cools.

2 (a) A Work flows...
A) into the gas **B)** out of the gas **C)** neither

2 (b) B The internal energy of the gas...
A) increases **B)** decreases **C)** stays the same

2 (c) B Heat flows...
A) into the gas **B)** out of the gas **C)** neither
D) can't tell without more information

10. The figure shows three spinners on a combination lock.



3 (a) How many possible combinations could the lock have?

$5 \times 3 \times 4 = \boxed{60}$

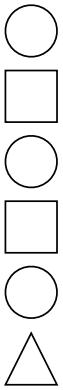
3 (b) Describe, in words, a macrostate of this lock with $\Omega > 1$.

"The first number is 1," "The sum of the digits is even," many other options

3 11. B Calculate $\binom{8}{5}$.
A) 1.6 **B)** 56 **C)** 112 **D)** 336 **E)** 792 **F)** 6720

$$\frac{8!}{5!3!} = \frac{8 \cdot 7 \cdot 6}{3 \cdot 2 \cdot 1} = 56$$

12. Consider three circles, two squares, and a triangle in a pile, as shown.



3 (a) How many different sequences can one make from these six shapes?

Rearrangement with duplicates: $\frac{6!}{3!2!} = \frac{6 \cdot 5 \cdot 4}{2} = \boxed{60}$

3 (b) If the shapes are being shuffled randomly, what is the probability that a circle is at the top?

If a circle is at the top, there are five remaining shapes, including two circles and two squares, for a total of

$$\Omega = \frac{5!}{2!2!} = \frac{5 \cdot 4 \cdot 3 \cdot 2 \cdot 1}{2 \cdot 2} = 30$$

and so

$$P = \frac{30}{60} = \boxed{50\%}$$

13. Consider a paramagnet with 10 dipoles. Let $U = 0, 1, 2, \ldots, 10$ be our "normalized energy".

3 (a) What is the multiplicity Ω of the paramagnet, if its energy is $U = 1$?

There are ten ways you can have exactly one dipole pointing upward, so $\boxed{\Omega = 10}$.

3 (b) A Which energy macrostate has the greater multiplicity?
A) $U = 5$ **B)** $U = 9$

3 14. What is the multiplicity of an Einstein solid with $N = 2$ oscillators and $q = 3$ quanta of energy?

$$\Omega = \binom{N+q-1}{q} = \binom{2+3-1}{3} = \binom{4}{3} = \frac{4!}{3!1!} = \boxed{4}$$

3 15. In the low-temperature limit $N \gg q \gg 1$, the multiplicity of an Einstein solid is approximately $\Omega = (eN/q)^q$. Find the approximate *entropy* of an Einstein solid when $N = 3 \times 10^6$ and $q = 10^6$ (assuming both qualify as big numbers).

The entropy is

$$S = k \ln \Omega = k \ln(eN/q)^q = kq \ln(eN/q) = kq\,(1 + \ln N - \ln q)$$

$$= (1.38 \times 10^{-23})(10^6)\left(1 + \ln(3 \times 10^6) - \ln(10^6)\right)$$

$$= (1.38 \times 10^{-17})(2.10)$$

$$= \boxed{2.9 \times 10^{-17}\ \text{J/K}}$$

4 16. The figure shows the multiplicity of an ideal gas with N particles, volume V, and internal energy U. In each of the blanks, indicate whether the corresponding factor is due to

A) The position microstates
B) The momentum microstates
C) The indistinguishability of the particles

$$\Omega = \frac{1}{N!}\,\frac{(2\pi m)^{3N/2}}{h^{3N}\left(\frac{3N}{2}\right)!}\,V^N\,U^{3N/2}$$

C B A B

3 17. A When gas leaks out of a hot-air balloon, the entropy of the gas
A) increases **B)** stays the same **C)** decreases