ASEN 1320 Fall 2020
Homework Assignment 2 - Gas Temperature and Heat Transfer (gas.cpp)
Due: 11:59pm on September 13 (Sunday)

Problem: In designing aerospace vehicles, thermodynamic performance is a prime consideration. This is because all vehicles operate by transforming the stored work potential contained in fuel into useful work. This work output is then used to overcome various loss mechanisms in the engine, drivetrain, and vehicle systems. The laws of thermodynamics help estimate the potential for thermo-mechanical energy conversion, thus playing important roles in engineering design and analysis of aerospace vehicles.

Many principal concepts of thermodynamics are derived from the kinetic theory of gases which describe the thermodynamic behavior of gases. Let's consider a gas of N particles, each of mass m, enclosed in a certain volume. According to the kinetic theory of gases, the temperature T in Kelvin (K) of an ideal gas is related to the average kinetic energy per particle through the relation:

$$\frac{3}{2}k_B T = \frac{m}{2N}(v_1^2 + v_2^2 + \cdots + v_N^2) \ ,$$

where Boltzmann's constant is $k_B = 1.38064852 \cdot 10^{-23}$ in Joule per Kelvin (J/K) and each particle with mass m in kilogram (kg) is travelling at velocity $v_1, v_2, \cdots, v_N$ meter per second (m/s). This can be written as

$$T = \frac{m}{3k_B N}(v_1^2 + v_2^2 + \cdots + v_N^2) \ . \tag{1}$$

If two gases that are initially at different temperatures are brought together, they eventually achieve thermal equilibrium through heat conduction. Heat conduction is the direct microscopic exchange of kinetic energy of particles. During the process of reaching thermal equilibrium, heat is transferred between the gases. The amount of heat transferred ΔQ in Joule (J) is proportional to the temperature difference ΔT between these gases. For a mole of the gas, the heat transfer is

$$\Delta Q = c N_A m \Delta T \tag{2}$$

where c is the specific heat capacity in Joule per kilogram per Kelvin (J/kgK), Avogadro's constant N_A is $6.02214076 \cdot 10^{23}$.

Tasks: Write a C++ program that (i) asks the user for a number N of gas particles and their minimum and maximum speeds v_{min} and v_{man} as well as the temperature of surrounding air T_s. (ii) Have the program generate random speeds $v_1, v_2, \cdots, v_N$ between the minimum and maximum for each of N particle, and compute the gas temperature T_g using Equation (1) and output it to the console. Use m for H_2, which is 2×1.00784 atomic mass unit (AMU) where AMU is $1.660538921 \cdot 10^{-27}$ kg. (iii) Compare the gas temperature T_g to the ambient air temperature T_a, and output to the console how much heat ΔQ would be transferred to or away from if the hydrogen gas reaches thermal equilibrium with the surrounding air using Equation (2). Use $\Delta T = T_s - T_g$, and the specific heat $c = 1000.0$ (J/kgK).

Here are some details.

- Submit a C++ program source file named **gas.cpp** to Gradescope.
- All the computation should be done just in `main ()` using the `iostream`, `string`, `cmath`, and `cstdlib` libraries if needed.
- Prompt the user for input values for N, v_{max}, v_{min}, and T_s with the following messages "Enter the number of particles: ", "Enter the minimum velocity in m/s: ", "Enter the maximum velocity in m/s: ", and "Enter the temperature of surrounding air in K: " in this order. Each message should start on a new line.
- The user's input values are expected to be `double` except for the number of particles N which should be `int`.
- The console output of the gas temperature T_g needs to be rounded up or down to the nearest integer number, and accompanied with the message "The gas temperature in K: XXX"
- Avodadro's constant is the number of particles contained in a unit known as a mole. A mole of gas occupies 22.4 L at standard temperature and pressure. This is a constant, so it can be declared and initialized as, for example, `const double Na = 6.02214076e+23`.
- Inform the user what kind of heat transfer would take place for a given set of inputs by printing the following messages: "No heat transfer" when ΔQ is zero, "Heat is transferred from the surrounding air to the gas" when ΔQ is positive, and "Heat is transferred away from the gas to the surrounding air" when ΔQ is negative. ΔQ needs to be rounded up or down to the nearest integer number before being used as conditions.
- Inform the user of the heat transfer amount ΔQ when ΔQ is not zero. The console output of the ΔQ value needs to be rounded up or down to the nearest integer number, and accompanied with the message "The transferred heat in J: XXX".
- Make sure to initialize the initialize the random number generator seed using `srand (1)` for the Gradescope submission.

Sample examples of console output from 3 separate runs

- Run 1

```
Run    Command: hw3/gas.cpp

Running /home/ec2-user/environment/hw3/gas.cpp
Enter the number of particles: 10000
Enter the minimum velocity in m/s: 1000
Enter the maximum velocity in m/s: 3000
Enter the temperature of surrounding air in K: 390
The gas temperature in K: 348
Heat is transferred from the surrounding air to the gas
The transferred heat in J: 84


Process exited with code: 0
```

- Run 2

```
Run    Command: hw3/gas.cpp

Running /home/ec2-user/environment/hw3/gas.cpp
Enter the number of particles: 10000
Enter the minimum velocity in m/s: 1000
Enter the maximum velocity in m/s: 3500
Enter the temperature of surrounding air in K: 390
The gas temperature in K: 448
Heat is transferred away from the gas to the surrounding air
The transferred heat in J: -118


Process exited with code: 0
```

- Run 3

```
Run    Command: hw3/gas.cpp

Running /home/ec2-user/environment/hw3/gas.cpp
Enter the number of particles: 10000
Enter the minimum velocity in m/s: 999
Enter the maximum velocity in m/s: 3000
Enter the temperature of surrounding air in K: 348
The gas temperature in K: 348
No heat transfer


Process exited with code: 0
```