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Variation of the Speed of Sound in Monoatomic Gases with Altitude and Humidity

Research Project

Submitted to the department of physics in partial fulfillment of the requirements for the degree of BSc. In Physics.

By

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Apirl 2024

بسم الله الرحمن الرحيم

" وما أوتيتم من العلم إلا قليلا"

صدق الله العظيم

(سورة الاسراء الاية 85)

Supervisor Certificate

This research project has been written under my supervision and has been submitted for the award of the degree of BSc. in (Physics).

Signature

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Date / /2024

I confirm that all requirements have been completed.

Signature

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Date / /2024

This project is dedicated to:

Respectful Parents

Dear Brothers and Sisters

Lovely Nieces and Nephews

Eman

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My most gratefulness and respect to my parents.

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CONTENTS

Abstract

We made an attempt to calculate how the speed of sound for monoatomic gases changes as a function of altitude in the normal region above sea level as the relevant data was taken at altitude ≤ 11 Km. The gravitation of earth at each layer taken into consideration. Also in This research describes the influence of humidity on the speed of sound in standard atmosphere at various temperature.

Chapter One

1. Introduction

The effect of gravity on the propagation of sound in a gas was first studied by (Rayleigh,1954) about a century ago. He started with the assumption of an adiabatic atmosphere under gravitational stress.

Knowledge of the thermo physical properties of hydrocarbons is of high importance in various fields of science and technology. As the direct measurement and calculation of properties such as density and heat capacity is quite difficult at elevated pressures, an indirect approach may work better. Acoustic method may be one of such techniques in which the speed of sound can be measured as a function of both temperature T and pressure P. Additionally, the speed of sound is related to derivatives of the thermodynamic properties in equation of states. Speed of sound data will give direct and precise information on the adiabatic properties of a gas.

The earliest reasonably accurate estimate of the speed of sound in air was made by William Derham and acknowledged by Isaac Newton. Derham had a telescope at the top of the tower of the Church of St Laurence in Upminster, England. On a calm day, a synchronized pocket watch would be given to an assistant who would fire a shotgun at a pre-determined time from a conspicuous point some miles away, across the countryside. This could be confirmed by telescope. He then measured the interval between seeing gun smoke and arrival of the sound using a half-second pendulum. The distance from where the gun was fired was found by triangulation, and simple division (distance/time) provided velocity. Lastly, by making many observations, using a range of different distances, the inaccuracy of the half-second pendulum could be averaged out, giving his final estimate of the speed of sound. Modern stopwatches enable this method to be used today over distances as short as 200–400 meters, and not needing something as loud as a shotgun.

A long range sound propagation topic which has received recent attention is the propagation of sounds through the atmosphere at high altitudes (Besset and Blanc, 1994). Altitudes of concern include the thermosphere up to about 160 km. Secondary sonic booms from proposed supersonic transports, a source of potentially annoying low frequency sounds on the ground (Poling, et al., 1997), can propagate initially upward before being refracted down to the ground. Sounds generated by atmospheric explosions can also travel along a path that goes up to the thermosphere giving rise to shadow zones on the ground spaced by thou- sands of miles. For purposes of monitoring nuclear explosions or supersonic aircraft, waves that travel upward to the thermosphere and then turn back to the ground are very important—often that is the only arrival. Absorption of sound at such altitudes involves atmospheric conditions very different from those normally encountered near, or on, the ground.

New algorithms, not previously available for predicting atmospheric absorption of sound at high altitudes (up to about 160 km) have been developed. At such high altitudes, classical and rotational relaxation absorption are dominant, as opposed to absorption by molecular vibrational relaxation that is the primary atmospheric absorption loss mechanism for primary sonic booms propagating directly down from a supersonic aircraft to the ground. Classical and rotational relaxation absorption varies inversely with atmospheric pressure, thus increasing in magnitude at high altitudes. For the latter, the relaxation frequencies vary directly with atmospheric pressure and depend on moisture content which rap- idly decreases at high altitudes. However, classical and rotational motion also relax at the high values of frequency/ pressure reached at high altitudes and thus, for audio and infrasonic frequencies, absorption due to these mechanisms begins to decrease at altitudes above 90 km.

The analysis of atmospheric absorption of sound at high altitudes treats the variation in the mole ratios of the atmospheric constituents in two ways. For molecular relaxation, this variation has a primary effect and it is considered explicitly using polynomial fits to published data to define the variation in mole ratios (or mole fractions) as a function of altitude. This includes, for the first time, consideration of the added effects of molecular relaxation loss by carbon dioxide and ozone. The algorithms also include, for all four of these gases, an accurate assessment of temperature effects on their molecular vibration relaxation frequencies (Bass, 1981). For evaluation of classical plus rotational relaxation loss, the effect of this high altitude variation in the proportion of atmospheric constituents on viscosity and specific heat ratio at high altitudes is assumed to be of second order and is not considered in this paper. While methods are available to take such effects into account, they are complex and their application should not lend further insight into the first-order effects. Furthermore, the authors are not aware of data that would validate the application of these complex methods to predict viscosity at altitudes above the stratosphere.

It should be noted that standard values in the 1962 US Standard Atmosphere for atmospheric parameters, such as viscosity, at altitudes above 90 km. Thus, as stated earlier, the viscosity-dependent values for classical and rotational relaxation losses at altitudes above 90 km must be considered only as best estimates. Nevertheless, these estimates do account accurately for the dominant effect of temperature on viscosity assuming a constant atmospheric composition. One atmospheric attenuation effect that was not considered due to its negligible contribution is thermal radiation (Bass, et al., 1984).

The thermosphere is a complex and externally-forceddeterministic system [*Forbes*, 2007]. These forces include solar EUV radiation [*Rishbeth et al.*, 2000], high-latitude electrodynamics [*Killeen and Roble*, 1988], particle precipitation [*Akasofu*, 1976] and waves propagating from the lower atmosphere [*Hines*, 1967]. In the last several decades,many modeling efforts have been made to improve to our understanding of this complex thermosphere system. Some of the well-known global thermosphere models are the Thermosphere Ionosphere Electrodynamic General Circulation Model (TIEGCM) and its predecessors [*Richmond*,1992).

In many GCMs, the gravitational acceleration (*g*) is set to be a constant in a hydrostatic atmosphere. With this assumption, the column mass density between two pressure levels (ΔP) is constant (ρΔz = - ΔP/g), where ρ is the mass density and Δz is the altitude difference between two pressure levels. The continuity equation in the pressure coordinates can be simplified as the divergence of the velocity (U) equals to zero (ΔU= 0) (Holton, 1992) assuming hydrostatic equilibrium and constant gravity. The constant ~g assumption is valid in the low-middle atmosphere models since the vertical extent of the low-middle atmosphere is only several tens of kilometers, resulting in only a 1% error in the specification of ~g. However, in the upper atmosphere, where the altitude range covers several hundred kilometers (100 – 500 km), the decrease of the gravitational acceleration with altitude may not be negligible, and can impact the thermosphere through changing the scale height (H=KT/mg) where k is the Boltzmann constant, T is the temperature, m is the mean molecular mass and g is the gravitational acceleration). In order to more accurately simulate the thermosphere, an altitude-dependent ~g should be used in GCMs. However, it may not be easy for the models using pressure coordinates to change to the altitude-dependent ~g, since the mass conservation between pressure levels would not be valid anymore and the continuity equation would need to be reformulated (Holton, 1992).

Therefore, it is very important to evaluate how strongly the constant gravitational acceleration specification can affect the thermosphere simulations. This may be a significant source of discrepancy when conducting neutral density data-model comparisons, since there may be a systematic error when ~g is assumed to be a constant throughout the thermosphere. Some non-hydrostatic thermosphere models using a variable ~g are available in the community (Demars and Schunk, 2007). However, they are either a 2-D model (Chang and St.-Maurice, 1991), or without a self-consistent ionosphere (Ma and Schunk, 1995). altitude coordinates, the influence of the altitudinal variation of ~g on thermosphere simulations has been investigated under different geomagnetic conditions.

The speed of sound is the distance travelled per unit of time by a sound wave as it propagates through an elastic medium. At 20 °C, the speed of sound in air is about 343 meters per second. It depends strongly on temperature as well as the medium through which a sound wave is propagating. At 0 °C (32 °F), the speed of sound is about 331 meters per second.

The speed of sound in an ideal gas depends only on its temperature and composition. The speed has a weak dependence on frequency and pressure in ordinary air, deviating slightly from ideal behavior.

In colloquial speech, speed of sound refers to the speed of sound waves in air. However, the speed of sound varies from substance to substance: typically, sound travels most slowly in gases, faster in liquids, and fastest in solids. For example, while sound travels at 343 m/s in air, it travels at 1,481 m/s in water (almost 4.3 times as fast) and at 5,120 m/s in iron (almost 15 times as fast). In an exceptionally stiff material such as diamond, sound travels at 12,000 meters per second (39,000 ft/s), (Dean, 1979) about 35 times its speed in air and about the fastest it can travel under normal conditions.

Sound waves in solids are composed of compression waves (just as in gases and liquids), and a different type of sound wave called a shear wave, which occurs only in solids. Shear waves in solids usually travel at different speeds than compression waves, as exhibited in seismology. The speed of compression waves in solids is determined by the medium's compressibility, shear modulus and density. The speed of shear waves is determined only by the solid material's shear modulus and density.

Sir Isaac Newton's 1687 Principia includes a computation of the speed of sound in air (298 m/s). This is too low by about 15%. (Wong and Zhu, 1995). The discrepancy is due primarily to neglecting the (then unknown) effect of rapidly-fluctuating temperature in a sound wave (in modern terms, sound wave compression and expansion of air is an adiabatic process, not an isothermal process). This error was later rectified by Laplace (Bannon and Kaputa, 2014).

During the 17th century there were several attempts to measure the speed of sound accurately, including attempts by Marin Mersenne in 1630 (420.624 m/s), Pierre Gassendi in 1635 (448.970 m/s) and Robert Boyle (342.9). In 1709, the Reverend William Derham, published a more accurate measure of the speed of sound, at 326.745 m/s. the speed of sound at 20 °C =321.564 m/s.

Chapter Two

2. Theory

2. 1 Factors affecting the velocity of sound

We proceed in a manner analogous to (Richardson, 1963) in order to set up the differential equation for a longitudinal wave disturbance traveling along the z- direction within the gas . Let f(z,t) be displacement produced at height z at time t. The net elastic restoring force on a strip of cross sectional area s and width dx is,

$$s\frac{\partial}{\partial z}\left(E\frac{\partial f}{\partial z}\right)dz, \quad (1)$$

Whereas the net external force on this strip of mass (ρsdz) equals,

$$-\frac{s\rho}{m}\frac{dW}{dz}dz, \quad (2)$$

W being the potential energy per molecule. Application of Newton's second law to the motion of this strip leads immediately to the desired inhomogeneous partial differential equation,

$$\rho\frac{\partial^2 f}{\partial t^2}-\frac{\partial}{\partial z}\left(E\frac{\partial f}{\partial z}\right)=-\frac{\rho}{m}\frac{dW}{dz}. \quad (3)$$

A general solution of Equ. (3) can be written as a sum of $f(z,t)=f_c(z,t)+f_p(z,t)$, where f_p is a particular integral of Equ. (3) obtained by using the retarded Green's function, f_c is the complimentary function satisfying the homogeneous equation,

$$\rho\frac{\partial^2 f_c}{\partial t^2}-\frac{\partial}{\partial z}\left(E\frac{\partial f_c}{\partial z}\right)=0. \quad (4)$$

For the purpose of finding the velocity we need to consider only the f_c function because it mainly describes the formation and propagation of progressive waves in the medium, while the f_p function describes the emission of extra casual waves associated with the source term on the right hand side of Equ. (3). Although Equ. (4) is of the same form as the wave equation for a free medium [ ] there is an important difference arising from the z dependence of ρ and E.

Let us seek a periodic solution of Equ. (4) in the form,

$$f_c(z,t) = u(z)/\sqrt{E}(z)e^{-iwt} + \text{complex conjugate,} \quad (5)$$

Where *w* is the angular frequency of the wave, and *u(z)* satisfies the exact differential equation,

$$\frac{d^2u}{dz^2} + (k_n^2 + k_a^2)u = 0 \quad (6)$$

With

$$k_n^2 = \frac{w^2\rho}{E} \quad \text{and} \quad k_a^2 = -\frac{1}{\sqrt{E}}\frac{d^2\sqrt{E}}{dz^2}. \quad (7)$$

Equation ( ) leads to,

$$f_c \approx \frac{Ae^{i\phi}}{(E\rho)^{1/4}} + \text{complex conjugate,} \quad (8)$$

Where

$$\phi \equiv \int^z dz\, k_n - wt \quad (9)$$

And ***A*** is some constant. The phase velocity of the wave in Equ. (8) is computed from,

$$c(z) \equiv \left| \frac{\partial\phi}{\partial t} \middle/ \frac{\partial\phi}{\partial z} \right| = \sqrt{\frac{E}{\rho}} = \sqrt{\gamma}v_3(z), \quad (10)$$

Which is again of the same from as for free gas (Richardson, 1963). However, Equ. (10) is valid only in the normal region where E and ρ are slowly varying.

The effect of gravity on the propagation of sound in a gas was first studied by (Lord Rayleigh, 1945) about a century ago. He started with the assumption of an adiabatic atmosphere under gravitational stress. The equation of statute for the system is,

$$p = \text{const}\,\rho^{\gamma}; \quad (11)$$

And the equation for the hydrostatic equilibrium reads

$$dp = -g\rho\, dz, \quad (12)$$

Where p, ρ, g, and z, respectively, the pressure, density, ratio of the specific heats at constant pressure to constant volume, the acceleration due to gravity, and altitude. The elimination of pressure between these two equations leads to the expression for the density,

$$\rho = \rho_0 \left(1 - \frac{\gamma - 1}{\gamma} \frac{\rho_0 g z}{p_0}\right)^{1/(\gamma - 1)}. \quad (13)$$

Here ρ_o and p_o are the density and the pressure at the ground where the gravitational potential is regarded to be zero. By differentiating the pressure with respect to the density and using Equ. (13), Rayleigh obtained the following expression for the velocity of sound,

$$C(z)=[C^2(0) - \gamma(\gamma-1)gz]^{1/2} \quad (14)$$

where C(0) is the velocity at the ground level.

for monoatomic gas $\gamma=(5/3)= 1.666$, and for non vibrating diatomic gas $\gamma=(7/5)=1.4$. The velocity of sound at $20C^o$ equal to 343 m/s.

In the case of a monoatomic gas $\gamma=(5/3)$, the equation (14) become,

$$C^2 (z)=C^2(0) - (2/3)\gamma gZ$$

The right hand side of Equ. (15) is proportional to the square root of the absolute temperature.

As is well known, standard kinetic theory (Resnick, and Halliday, 2013) of a free ideal gas (i.e., when there are no force acting on the molecules) leads to an expression for the velocity of sound in term of free elasticity E_o and density ρ_o as,

$$c_0 = (E_0/\rho_0)^{1/2} = (\gamma p_0/\rho_0)^{1/2}, \quad (16)$$

From which the effect of pressure, density, temperature, humidity, etc., follow as a natural consequence. When the gas is acted upon by gravity we anticipate that Equ. (16) will be so modified as if the sound itself experiences an acceleration of the order of g. This is in view of the fact that the molecules execute random mechanical motion under gravity and the molecular speeds are of the same order as the speed of sound (Resnick, and Halliday, 2013).

2. 2 Effect of Earth gravity by altitude

The acceleration due to gravity at an altitude above sea level calculated by the relation (Deng, et al., 2008),

$$g_{altitude}=g.[R_e/(R_e+Z)]^2 \quad (17)$$

where, Re is mean radius of earth, R_e=6371.009 km

Z is the altitude above sea level in meter.

$g_{altitude}$ is the acceleration due to gravity at specific altitude.

g is acceleration due to gravity at sea level.

$g=9.80665\ m/s^2$

2.3 The effect of humidity on speed of sound

The effect of humidity on speed of sound in gases at atmospheric pressure obtain by using the following approximate equation,

$$C_h/C_o= 1+h(9.66x10^{-4}+7.2x10^{-5}T+1.8x10^{-6}T^2+7.2x10^{-8}T^3+6.5x10^{-11}T^4 \qquad (18)$$

Where, C_h is the speed of sound under the influence of humidity, C_o is the speed of sound at atmosphere pressure, h is relative humidity (dimensionless) and T gas temperature in degrees Celsius.

2.4 Estimation, the method of least square fit

Estimation procedure, that was developed independently by Gauss (1795), Legendre (1805) and Adrain (1808) and published in the first decade of the nineteenth century.

The least-squares method is a form of mathematical regression analysis used to determine the line of best fit for a set of data, providing a visual demonstration of the relationship between the data points. Each point of data represents the relationship between a known independent variable and an unknown dependent variable. This method of regression analysis begins with a set of data points to be plotted on an x- and y-axis graph. An analyst using the least-squares method will generate a line of best fit that explains the potential relationship between independent and dependent variables.

The equation of least square line is given by $Y = a + bX$ (Sastry, 2012)

Normal equation for ‘a’:

$$\sum Y = na + b\sum X \qquad (19)$$

Normal equation for ‘b’:

$$\sum XY = a\sum X + b\sum X^2 \qquad (20)$$

Solving these two normal equations we can get the required trend line equation.

Thus, we can get the line of best fit with formula $y = ax + b$

Or

Formula for linear regression equation is given by:

$$y = a + bx \tag{21}$$

a and *b* are given by the following formulas:

$$a\,(intercept) = \frac{\sum y \sum x^2 - \sum x \sum xy}{(\sum x^2) - (\sum x)^2} \tag{22}$$

$$b\,(slope) = \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2} \tag{23}$$

Where,

x and *y* are two variables on the regression line.

b = Slope of the line.

a = *y*-intercept of the line.

x = Values of the first data set.

y = Values of the second data set.

The sample correlation coefficient formula is:

$$r_{xy} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n\sum x_i^2 - (\sum x_i)^2}\,\sqrt{n\sum y_i^2 - (\sum y_i)^2}} \tag{24}$$

The degree of association is measured by "r" after its originator and a measure of linear association. Other complicated measures are used if a curved line is needed to represent the relationship.

Chapter Three

3. Result and Discussion

The universal force of attraction among all the entities or matter in this universe is also known as gravity. It can be considered as the driving force which pulls together all the matter. Gravity is measured in terms of the acceleration or movement that it gives to freely falling objects. At Earth's surface, the value of the acceleration of gravity is about **9.8 m/s^2**. Thus, for every second an object is in free fall, its speed increases by about 9.8 m/s^2.
Factors affecting Acceleration due to Gravity
g is majorly affected by the following four factors:

1. The shape of the Earth.
2. Rotational motion of the Earth.
3. Altitude above the Earth's surface.
4. Depth below the Earth's surface.

The variation in apparent gravitational acceleration (*g*) at different locations on Earth is caused by two. First, the Earth is not a perfect sphere, it's slightly flattened at the poles and bulges out near the equator, so points near the equator are farther from the center of mass. The distance between the centers of mass of two objects affects the gravitational force between them, so the force of gravity on an object is smaller at the equator compared to the poles. This effect alone causes the gravitational acceleration to be about 0.18% less at the equator than at the poles.

Second, the rotation of the Earth causes an apparent centrifugal force which points away from the axis of rotation, and this force can reduce the apparent gravitational force. The centrifugal force points directly opposite the gravitational force at the equator, and is zero at the poles. Together, the centrifugal effect and the center of mass distance reduce *g* by about 0.53% at the equator compared to the poles.

Third, to calculate *earth gravitation at* a certain latitude, gravity decreases with altitude as one rises above the Earth's surface because greater altitude means greater distance from the Earth's center. All other things being equal, an increase in altitude from sea level to 9,000 meters causes a weight decrease of about 0.29%. (An additional factor affecting apparent weight is the decrease in air density at altitude, which lessens an object's buoyancy. This would increase a person's apparent weight at an altitude of 9,000 meters by about 0.08%).

The formula shown here approximates the Earth's gravity variation with altitude.

$g_{altitude}=g.[\ R_e/(R_e+Z)]^2$

where, R_e is mean radius of earth, R_e=6371.009 km

Z is the altitude above sea level in meter.

$g_{altitude}$ is the acceleration due to gravity at specific altitude.

g is acceleration due to gravity at sea level.

$g=9.80665\ m/s^2$

Figure 1 show the variation of gravity as function of altitude, which is explained in table 1. We see that as the altitude is rising the influence of the Earth's gravitational field on the speed of sound increases. The gravitational acceleration decreases with altitude, as shown by the solid line in figure. Earth gravity is equal to 9.7744 m/s^2 at 11 km altitude, which is less than gravity at sea level ($g=9.8066\ m/s^2$). The gravitational force above the Earth's surface is proportional to$1/R^2$, where R is your distance from the center of the Earth, gravity decreases with an increase in height and it becomes zero at an infinite distance from earth.

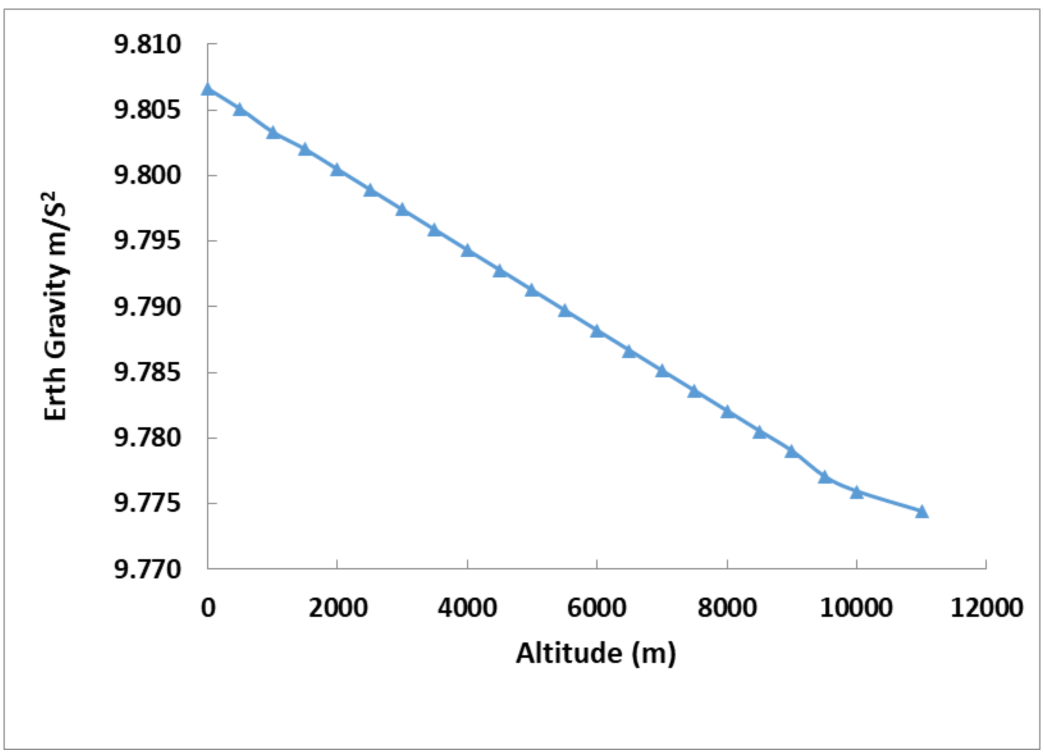

Figure 1: Variation of earth gravity against altitude.

Table 1: Variation of earth gravitation with altitude

Altitude (meter)	Earth Gravity m/s^2
0	9.80665
500	9.80511
1000	9.80335
1500	9.80203
2000	9.80049
2500	9.79895
3000	9.79742
3500	9.79588
4000	9.79434
4500	9.79281
5000	9.79127
5500	9.78974
6000	9.7882
6500	9.78667
7000	9.78513
7500	9.7836
8000	9.78206
8500	9.78053
9000	9.779
9500	9.77706
10000	9.77593
11000	9.7744

The starting point of our kinetic model has been a gas in thermal equilibrium in the sense that the averaged properties of the gas do not change with time and the energy equi-partition is built in. This generally means that the molecular mean free path is small compared to other characteristic distances. The fact that the total energy of a given molecule behaves in the same way as if no collisions are present is understandable because the molecules are regarded as perfectly elastic point like bodies.

It is noticed that the coefficient of gz in our formula [Eq. (14)] is $\gamma(\gamma -1)$ unlike $(\gamma-1)$ appearing in Rayleigh's formula, In the case of a monoatomic gas ($\gamma = 5/3$) our formula reduces to

$$C(z)=[C^2(0) - 1.111gz]^{1/2}.$$

The fact that the velocity of sound under gravity decreases with increasing altitude z is to be understood in terms of the variation of temperature from layer to layer as mentioned already in the Introduction

In figure 2 and 3 graphs represent the distribution of the true velocities of sounds in neon and helium monoatomic gases respectively along the altitude of the troposphere. We see that as the altitude is rising the influence of the Earth's gravitational field on the speed of sound increases.

Table 2 and 3 represents the altitude distribution of the values of the adiabatic and true velocities of sounds in neon and helium monoatomic gases respectively in the stratosphere.

Relative errors between the values of the true and adiabatic speeds of sound and the corresponding least square fit are also presented in the table. As seen, the relative error in determining the speed of sound at an altitude of 11 km is greater than at an altitude of 1 km.

The variation of the speed of sound with humidity for temperatures from 0 ^oC to 50 ^oC in step of 5 ^oC is shown in figure 4. It can be seen that C_h increases with humidity and temperature.

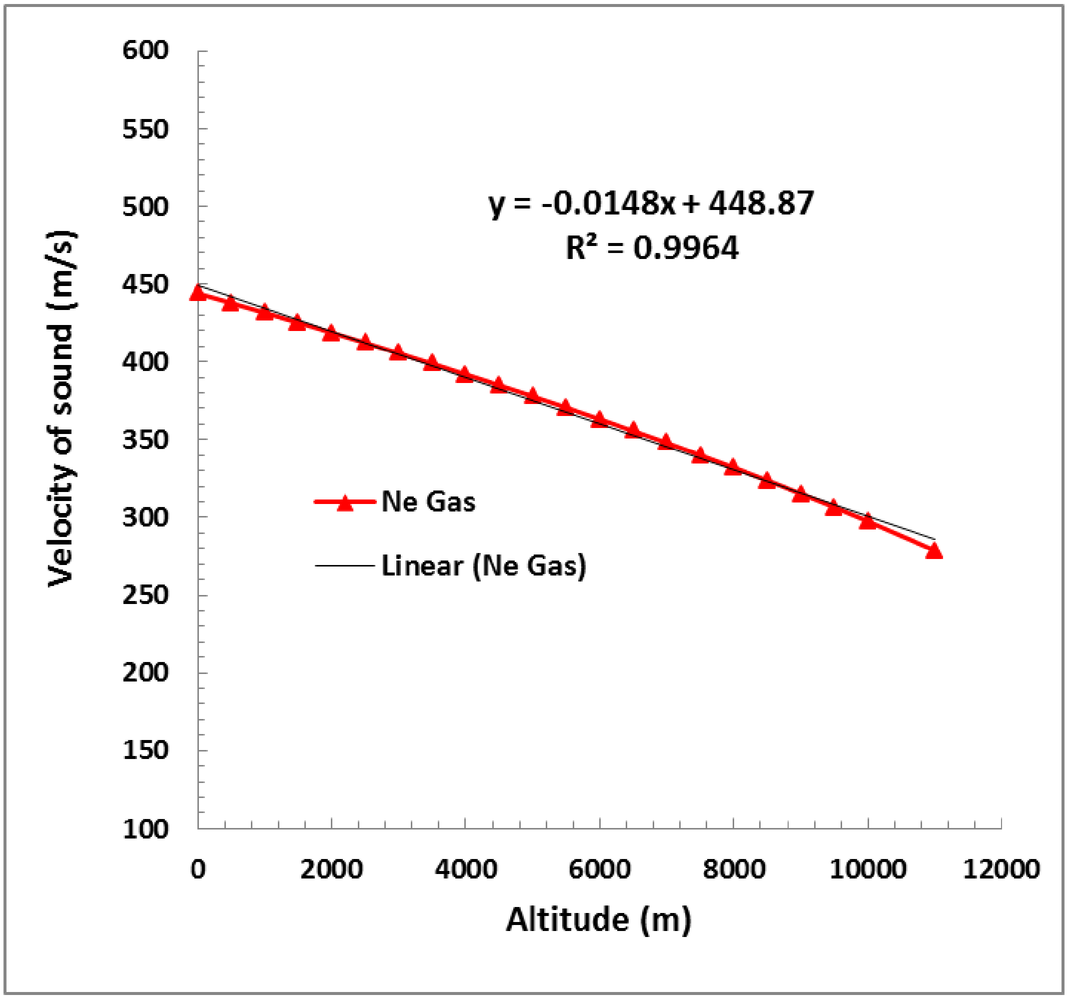

Figure 2: Velocity of sound against the altitude for Neon monatomic gas.

Table 2: Variation of the velocity of sound with altitude for Neon monoatomic gas

Altitude (m)	Earth gravitation m/s^2	Velocity of sound C(z) (m/s)	Velocity of sound (m/s) due to simulation fitting	Error%
0	9.81	444.03	448.48	1.00
500	9.81	437.85	441.13	0.75
100	9.80	431.59	433.78	0.51
1500	9.80	425.24	426.43	0.28
2000	9.80	418.79	419.08	0.07
2500	9.80	412.24	411.73	0.12
3000	9.80	405.59	404.38	0.30
3500	9.80	398.83	397.03	0.45
4000	9.79	391.96	389.68	0.58
4500	9.79	384.97	382.33	0.68
5000	9.79	377.84	374.98	0.76
5500	9.79	370.59	367.63	0.80
6000	9.79	363.19	360.28	0.80
6500	9.79	355.64	352.93	0.76
7000	9.79	347.93	345.58	0.68
7500	9.78	340.05	338.23	0.53
8000	9.78	331.98	330.88	0.33
8500	9.78	323.71	323.53	0.06
9000	9.78	315.23	316.18	0.30
9500	9.78	306.53	308.83	0.75
10000	9.78	297.56	301.48	1.32
11000	9.77	278.74	286.78	2.88

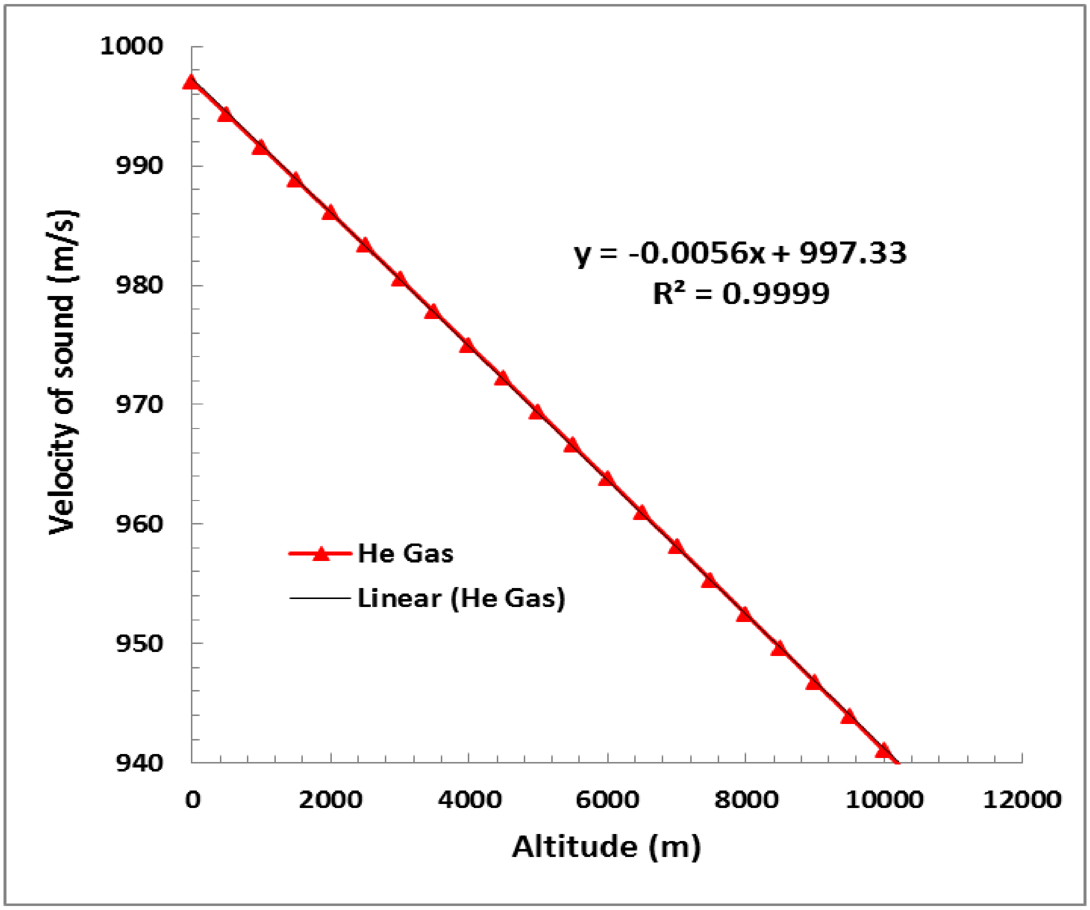

Figure 3: Velocity of sound against the altitude for Helium monatomic gas.

Table 3: Variation of the velocity of sound with altitude for Helium monoatomic gas

Altitude (m)	Earth gravitation m/s^2	Velocity of sound C(z) (m/s)	Velocity of sound (m/s) due to simulation fitting	Error%
0	9.81	997.07	997.33	0.03
500	9.81	994.33	994.53	0.02
100	9.80	991.59	991.73	0.01
1500	9.80	988.84	988.93	0.01
2000	9.80	986.09	986.13	0.00
2500	9.80	983.33	983.33	0.00
3000	9.80	980.56	980.53	0.00
3500	9.80	977.78	977.73	0.01
4000	9.79	975.00	974.93	0.01
4500	9.79	972.21	972.13	0.01
5000	9.79	969.41	969.33	0.01
5500	9.79	966.60	966.53	0.01
6000	9.79	963.79	963.73	0.01
6500	9.79	960.97	960.93	0.00
7000	9.79	958.15	958.13	0.00
7500	9.78	955.31	955.33	0.00
8000	9.78	952.47	952.53	0.01
8500	9.78	949.62	949.73	0.01
9000	9.78	946.76	946.93	0.02
9500	9.78	943.90	944.13	0.02
10000	9.78	941.02	941.33	0.03
11000	9.77	935.25	935.73	0.05

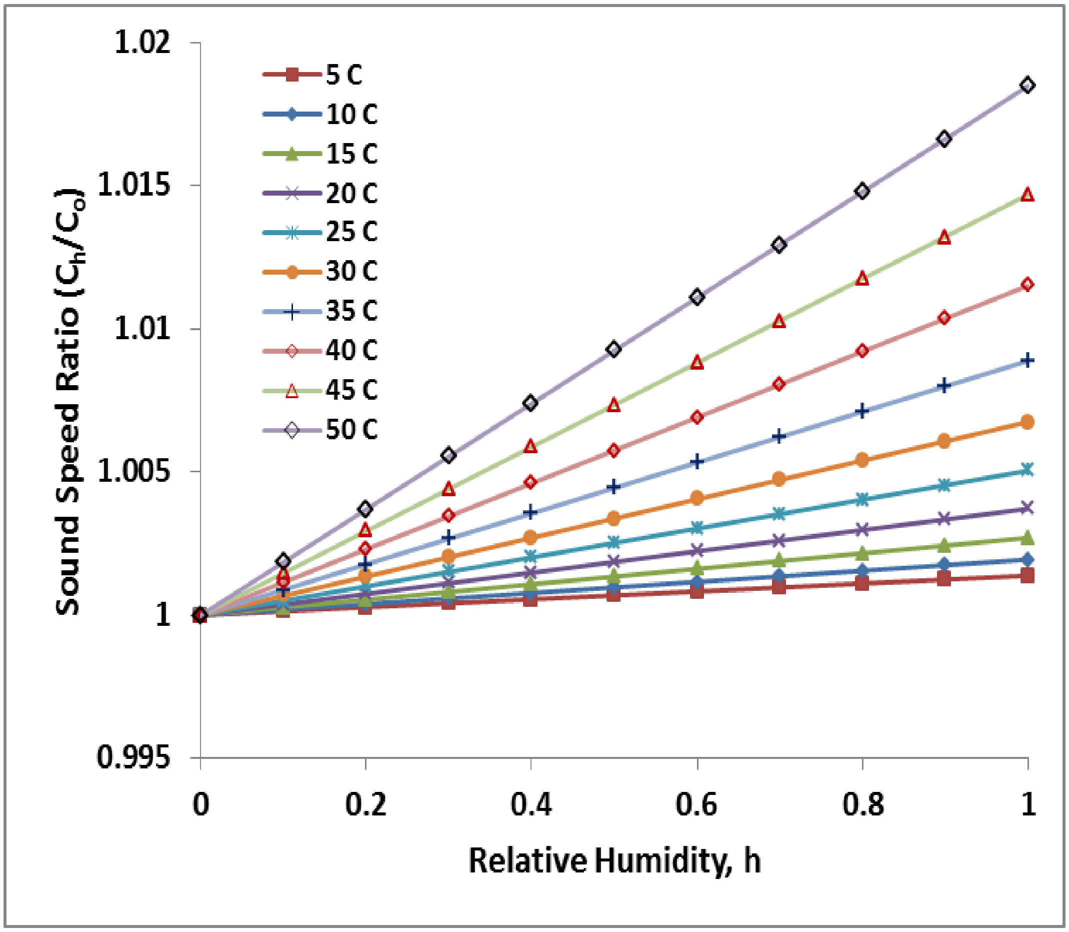

Figure 4. The effects of humidity on sound speed in air at various temperatures, at a pressure of 101.325 kPa.

Chapter Foure

4. Conclusion

We were able to successfully show that the speed of sound changes as a function of altitude in argon and helium monoatomic gases. Specifically, the earth gravitation and the speed of sound have a general positive correlation. Our data was only taken to about $\leq$ 11Km. The effect of humidity on the speed of sound in air at various temperature can be calculated from equation 18, the speed of sound increase with humidity and temperature.

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