THE REAL MEANING OF THE HUBBLE DIAGRAM

KARAN R.TAKKHI
Pune 411015, India
E-mail: karantakkhi007@gmail.com

ABSTRACT

The Hubble diagram continues to remain one of the most important graphical representations in the realm of astronomy and cosmology right from its genesis that depicts the velocity-distance relation for the receding large-scale structures within the observable Universe. The linear behaviour of the Hubble diagram has remained consistent right from the very beginning when it got plotted for the very first time. In this paper I unravel the real meaning of the Hubble diagram by introducing the molecular diffusion model in order to explain the expansion of the Universe. The molecular diffusion model considers the distribution of large-scale structures as molecules inside a vacuum chamber. Since large-scale structures are ensemble of atoms, therefore, they can be treated as molecules possessing finite amount of energy. Instead of considering that space is expanding, the paper emphasizes upon the actual recession of large-scale structures. The study conducted in this paper finds the recessional behaviour of large-scale structures to be consistent with the recessional behaviour of molecules.

Key words: cosmology: theory - dark energy - diffusion - Hubble diagram - Hubble's law - molecular data.

1 INTRODUCTION

The revolutionizing discovery by Sir Edwin Hubble in 1929 from his observations of distant galaxies from Mount Wilson Observatory in California not only proved that the Universe was expanding, it also paved a new way for modern astronomy and cosmology. The light from all the galaxies that were being observed was found to be redshifted, suggesting that the galaxies were moving away from one another and the Universe was expanding and was not at all "static" as was previously being considered.

Sir Edwin Hubble obtained a linear diagram by plotting the velocity-distance relation for the receding large-scale structures; a diagram that changed our perspective of the Universe forever…….the Hubble diagram. The linear relationship obtained while plotting the Hubble diagram depicts the Hubble's law according to which the recessional velocity of a large-scale structure is directly proportional to its distance, that is, the further away a large-scale structure is, the faster it will be receding away from us. The slope of the straight line yields the Hubble constant which was originally denoted by Sir Edwin Hubble by the letter *K*. The Hubble constant gives the rate of expansion of the Universe while its reciprocal gives the Hubble time or the age of the Universe.

The aim of this paper is to unravel the real meaning of the Hubble diagram on the basis of the molecular diffusion model which has been introduced in Section 2. Section 3 looks into the energy that causes the recession of large-scale structures. Section 4 shows that the large-scale structures possess energy by the virtue of which they recede. In Section 5 the recessional behaviour of large-scale structures is found to be in perfect agreement with the recessional behaviour of molecules, thereby suggesting the actual recession of large-scale structures. In Section 6 I discuss that the observed redshifts exhibited by large-scale structures are due to their actual recession rather than expansion of space between them, while Section 7 brings actual gas molecules into consideration to further study and compare the recessional behaviour of large-scale structures with gas molecules.

2 THE REAL MEANING OF THE HUBBLE DIAGRAM ON THE BASIS OF THE MOLECULAR DIFFUSION MODEL

Certain questions that should undoubtedly arise while looking at the Hubble diagram are - why is the Hubble diagram linear? In fact, why should it be linear? The Hubble diagram can be explained very effectively if we consider the distribution of large-scale structures as molecules inside a vacuum chamber. Since molecules recede by the virtue of the energy possessed by them, therefore, the same logic has been applied to the receding large-scale structures as well, that is, the large-scale structures recede by the virtue of the energy possessed by them instead of energy being possessed by empty space. Also, molecules undergo actual recession rather than expansion of space between them.

Since the large-scale structures are constituted by atoms and molecular matter, therefore, there is more probability that they will be possessing energy instead of energy being possessed by empty space. Now if receding large-scale structures are being considered as gas molecules, then they must exhibit certain properties or behaviour that should match with the properties or behaviour of actual gas molecules.

3 ENERGY THAT CAUSES THE DIFFUSION OR RECESSION OF A LARGE-SCALE STRUCTURE: WHY SHOULD A LARGE-SCALE STRUCTURE RECEDE ?

The energy possessed by an object moving with velocity v is given as,

$$E = \frac{1}{2}mv^2 \quad (1)$$

Equation (1) can be expressed in terms of velocity as,

$$v = \sqrt{\frac{2E}{m}} \quad (2)$$

Equation (2) suggests that an object possessing sufficient amount of energy will recede with certain velocity. This is exactly what is observed in the case of a molecule, that is, if the molecule gains more energy than before, then according to equation (2) the velocity of the molecule will increase. Now, since a large-scale structure possesses sufficient amount of energy (Section 4), therefore, such structure will recede with a velocity according to equation (2).

In an environment where gravitational force is stronger, like on Earth's surface, the energy possessed by an object will not cause the object to recede, as gravitational force takes over, however, a molecule is an exception in this case. Since the mass of a molecule is minuscule, therefore, a molecule is not influenced significantly by Earth's gravitational force; the energy possessed by a molecule turns out to be greater than the gravitational force acting upon it, and therefore the molecule recedes purely by the virtue of energy possessed by it. Similarly, in deep space environment since the large-scale structures readily recede away from one another, therefore, the gravitational influence between them has to be weaker than the energy possessed by the large-scale structures that causes them to recede.

According to equation (2), for a large-scale structure to exhibit higher recessional velocity, the energy possessed by it should be sufficiently large and the mass should be less. So if equal amount of energy is possessed by a galaxy and a galaxy cluster, then the galaxy will exhibit higher recessional velocity as compared to the galaxy cluster. On the other hand, if the recessional velocity of a galaxy and a galaxy cluster are equal, then the galaxy will be found to possess less amount of energy as compared to the galaxy cluster (Section 4).

4 THE ENERGY POSSESSED BY A LARGE-SCALE STRUCTURE

Large-scale structures recede by the virtue of the energy possessed by them instead of energy being possessed by empty space. To validate this claim consider a galaxy cluster. Since the mass of galaxy clusters usually ranges between 10^{14} M$_\odot$ and 10^{15} M$_\odot$, therefore, it would be perfectly fine to consider a galaxy cluster with mass of about 2 x 10^{15} M$_\odot$ (4 x 10^{45} kg). From this mass we obtain the total number of protons making the cluster to be 2.3914 x 10^{72} (ignoring dark matter).

The temperature of massive galaxy clusters is dominated by the extremely hot intracluster medium (ICM) at 10^8 K. The energy per molecule, in this case the proton is given as,

$$E = \frac{3}{2}kT \quad (3)$$

where k is the Boltzmann constant and T is the temperature. Using equation (3), we obtain the energy per proton corresponding to a temperature of 10^8 K to be 2.0709 x 10^{-15} J. Total energy possessed by the galaxy cluster therefore equates to 4.9523 x 10^{57} J.

Now, using equation (2), we will obtain the value of recessional velocity that the cluster will attain, and this is found to be 1,573,578.724 m s^{-1} (1.5 x 10^6 m s^{-1}). This is just an approximation. For comparison, the recessional velocity of Norma Cluster is 4,707 km s^{-1} (4.707 x 10^6 m s^{-1}) (NED 2006 results). Higher recessional velocities are also possible if the energy possessed by the large-scale structure is sufficiently large and the mass is less. For instance, for a 2 x 10^{15} M$_\odot$ (4 x 10^{45} kg) galaxy cluster to exhibit recessional velocity of 7 x 10^6 m s^{-1}, the energy possessed by it must be 9.8 x 10^{58} J. On the other hand, for a 10^{10} M$_\odot$ (2 x 10^{40} kg) galaxy to exhibit an equal recessional velocity of 7 x 10^6 m s^{-1}, the energy possessed by it must be 4.9 x 10^{53} J (2 x 10^5 times less energy than the energy possessed by the massive galaxy cluster).

It has been observed that the most distant celestial objects (billions of light-years away) exhibit very high recessional velocities as evident from their redshifts. Such distant structures reveal themselves to us as they were billions of years ago when the Universe was comparatively younger than it is today. Since the early Universe was much more energetic than it is today, therefore, it is very likely that the structures during that energetic era possessed surplus amount of energy that made them recede with such high recessional velocity. We do not know the present day recessional velocity of such distant celestial objects since we are observing them how those structures were billions of years ago. Therefore, it would be more accurate if we obtain the instantaneous amount of energy possessed by a large-scale structure from its instantaneous recessional velocity, after all, it is the energy possessed by the large-scale structure that is causing it to recede.

5 RECEDING LARGE-SCALE STRUCTURES AND RECEDING GAS MOLECULES EXHIBIT A SIMILAR BEHAVIOUR

It is always observed that the highest recessional velocities are exhibited by the most distant galaxies and not by galaxy clusters as evident from their redshifts. Galaxy clusters being extremely massive are unable to efficiently utilize the energy possessed by them to exhibit such high recessional velocities as those exhibited by such distant galaxies which comparatively are very much less massive than galaxy clusters. This is in perfect agreement with the recessional behaviour of molecules, that is, a lighter molecule recedes faster as compared to a massive molecule even when they both possess an equal amount of energy (see Table 2; Graph 1 and Table 3; Graph 2). A lighter molecule will therefore cover a larger distance with time as compared to the massive molecule; a lighter molecule will therefore become the most distant molecule as compared to the massive molecule (see Graphs 1 to 5). Galaxies being less massive than galaxy clusters exhibit higher recessional velocities and therefore they manage to become the most distant structures within the observable Universe. The recessional behaviour of large-scale structures being consistent with the recessional behaviour of molecules suggests the actual recession of large-scale structures and validates the credibility of the molecular diffusion model to some extent.

6 IS SPACE BETWEEN LARGE-SCALE STRUCTURES EXPANDING, OR ARE THE LARGE-SCALE STRUCTURES RECEDING ?

It is firmly believed that large-scale structures are stationary and only the distance between them is increasing, that is, the space between the large-scale structures is expanding, thereby causing the light emitted by them to get stretched (redshifted). Such firm belief arises undoubtedly due to the fact that nothing can travel faster than light. However, if the large-scale structures are actually receding away from each other, just like molecules, then the light emitted by them would still undergo redshifting due to the involvement of actual recession rather than expansion of space between them.

Since the recessional behaviour of large-scale structures is found to be consistent with the recessional behaviour of molecules as discussed in the previous section, therefore, the light from a very distant galaxy is redshifted to higher extent as compared to the light from a galaxy cluster (galaxy being less massive than a galaxy cluster exhibits higher recessional velocity); such consistent behaviour of large-scale structures with molecules suggests their actual recession rather than expansion of space between them.

7 PLOTTING THE GAS MOLECULES

Eleven gaseous elements from the Periodic Table, right from Hydrogen to Radon have been considered to prove the molecular diffusion model. The mass of the gas molecules has been obtained in Table 1. The mass of gas molecules increases from Hydrogen onwards; Hydrogen is the least massive molecule, whereas Radon is the most massive molecule. Hydrogen molecule can therefore be considered analogous to a galaxy, whereas Radon molecule can be considered analogous to a massive galaxy cluster. All these gas molecules are initially concentrated before diffusing or expanding freely inside a vacuum chamber. The gas molecules will recede inside the vacuum chamber by the virtue of the energy possessed by them at particular temperature as given by equation (3), while their recessional velocity due the energy possessed by them is given by equation (2). Equation (2) is also in agreement with the actual velocity equations for gas molecules given as,

$$v = \sqrt{\frac{3RT}{M}} \tag{4}$$

and,

$$v = \sqrt{\frac{3kT}{m}} \tag{5}$$

where R is the gas constant, T is the temperature, M is the molecular mass (kg mol^{-1}) of the gas, that is, M/1000 (see M from Table 1), k is the Boltzmann constant and m is the mass of the molecule in kg.

In Table 2, all gas molecules are at same temperature of 303 K, the energy possessed by every molecule will therefore be equal. The recessional velocity of the molecules is obtained from equation (2) and the distance covered by them in 1 second (observation time) has been calculated. In Table 3, all molecules are still at the same temperature of 303 K, however, the observation time has been increased to 60 seconds (distance covered by the gas molecules in 60 seconds). In Table 4, the observation time is 1 second, every molecule is at a random temperature and therefore, the energy possessed by the molecules will also be random. In Table 5, the molecules still remain at random temperature, however, the observation time has been increased to 60 seconds. In Table 6, the gas molecules are subjected to extreme random temperature, the energy possessed by the molecules will be highly random as compared to previous settings; the observation time in this case is 60 seconds.

From the tables (Table 2 to Table 6), the velocity-distance relation for the gas molecules has been plotted (Graph 1 to Graph 5). Surprisingly, the straight line obtained is remarkably similar to the straight line obtained in the Hubble diagram (depiction of Hubble's law) (Figure 1) which is also the velocity-distance relation plot for the receding large-scale structures. According to the Hubble's law, the recessional velocity of a large-scale structure is directly proportional to its distance, that is, the further away a large-scale structure is, the faster it will be receding away from us. Therefore, according to the Hubble's law,

$$v = H \text{ x } D \tag{6}$$

and,

$$D = \frac{v}{H} \tag{7}$$

where v is the recessional velocity of the large-scale structure, D is its distance from us and H is the Hubble constant. The reciprocal of the Hubble constant (H) gives us the Hubble time which is the age of the Universe.

Now this is found to be true for the gas molecules under consideration as well. From the tables (Table 2 to Table 5) and graphs (Graph 1 to Graph 4), it can be seen that the highest recessional velocity is exhibited by the Hydrogen molecule, followed by Helium, whereas the lowest recessional velocity is found to be exhibited by the Radon molecule. Hydrogen molecule being less massive exhibits higher recessional velocity as compared to the massive Radon molecule. In Table 6; Graph 5, the highest recessional velocity is still being exhibited by the Hydrogen molecule. Helium which previously remained the second fastest receding molecule behind Hydrogen has been replaced by Nitrogen. Similarly, Radon which previously remained the slowest receding molecule has been replaced by Xenon. Such change has occurred due to the involvement of large temperature differences. Such large differences in temperature influence the energy possessed by the molecules, thereby affecting their recessional velocities too. But no matter how the data changes for the gas molecules, the graphs continue to remain highly linear. Therefore, just like the Hubble's law, we can say that the recessional velocity of gas molecules is directly proportional to their distance, that is, the further away a molecule is, the faster it is receding away from us. The Slope of this straight line is also remarkably similar to the Hubble constant (H) (the slope of Hubble diagram) since its reciprocal gives us the observation time in seconds, just like the Hubble time obtained from the reciprocal of *H*. Furthermore, the following equations,

$$v = Slope \times D \tag{8}$$

and,

$$D = \frac{v}{Slope} \tag{9}$$

are also found to be obeyed by the gas molecules (Table 7 to Table 16) just like the receding large-scale structures. In the above equations, *v* is the recessional velocity of the molecules and *D* is the distance covered by the molecules within the given time frame. Since the velocity-distance relation plot for receding large-scale structures is similar to the velocity-distance relation plot for receding gas molecules, therefore, the molecular diffusion model holds good for the receding large-scale structures. The gas molecules and the large-scale structures get segregated in terms of velocity and distance according to their mass and the energy possessed by them.

Plotting the velocity-distance relation for receding gas molecules is same as plotting the velocity-distance relation for receding large-scale structures (the Hubble diagram). If we were able to observe the receding gas molecules and plot them in terms of velocity-distance relation then we will get the Hubble diagram. Also, it can be seen from the molecular plots that no matter on which molecule we would be situated upon, all molecules will exhibit redshift, just like the receding large-scale structures.

Plotting the velocity-distance relation plot for receding large-scale structures (the Hubble diagram) is same as plotting the velocity-distance relation plot for receding gas molecules, and this is exactly the real meaning of the Hubble diagram, the similar linear relationship obtained while plotting the velocity-distance relation plot for the receding large-scale structures and the receding gas molecules is not any coincidence, it is only because the receding large-scale structures behave like receding gas molecules that the plots turn out to be remarkably same.

Since gas molecules exhibit Hubble diagram and obey all Hubble equations solely due to their recession by the virtue of the energy possessed by them, therefore, the large-scale structures that are known to exhibit Hubble diagram and obey all Hubble equations have to be receding solely by the virtue of the energy possessed by them.

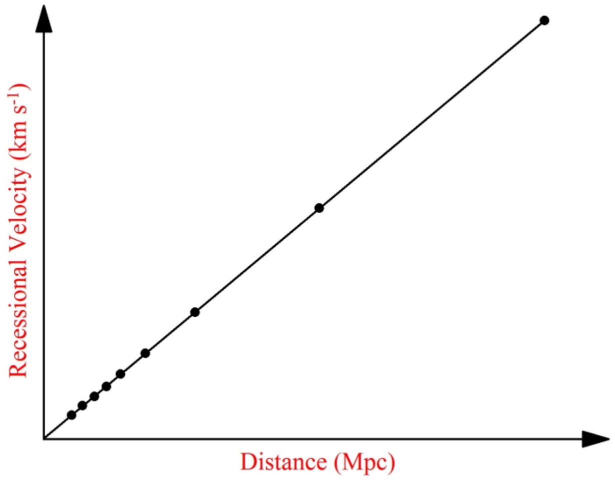


Figure 1. The Hubble diagram. Velocity-distance relation plot for receding large-scale structures. The slope of the straight line is the Hubble constant (*H*). The reciprocal of the Hubble constant (*H*) gives us the age of the Universe (Hubble time). The Hubble diagram depicts the Hubble's law according to which the recessional velocity of large-scale structures is directly proportional to their distance. Note that the velocity-distance relation plots for receding gas molecules (Graph 1 to Graph 4) are exactly like the velocity-distance relation plot for receding large-scale structures according to the Hubble diagram; the molecules receding slowly (molecules that are closer to us) get plotted close to one another as compared to the molecules that exhibit higher recessional velocity (molecules that are further away from us). Also, nearby molecules are massive, whereas distant molecules are lighter. Graph 5 remains linear but the distributional pattern of molecules is different from other graphs due to large differences in temperature and energy possessed by the molecules.

Table 1. Mass of gas molecules

Gaseous Elements	Atomic Mass (A) a.m.u. or g mol^{-1}	Molecular Mass (M) a.m.u. or g mol^{-1}	Mass of Molecule $(M/N_A)/1000$ kg
H	1.0079	2.0158	3.3473×10^{-27}
He*	4.0026	8.0052	1.3292×10^{-26}
N	14.0067	28.0134	4.6517×10^{-26}
O	15.9994	31.9988	5.3135×10^{-26}
F	18.9984	37.9968	6.3095×10^{-26}
Ne*	20.1797	40.3594	6.7018×10^{-26}
Cl	35.4530	70.9060	1.1774×10^{-25}
Ar*	39.9480	79.8960	1.3267×10^{-25}
Kr*	83.7980	167.5960	2.7829×10^{-25}
Xe*	131.2930	262.5860	4.3603×10^{-25}
Rn*	222.0000	444.0000	7.3727×10^{-25}

$N_A = 6.02214199 \times 10^{23}$ (Avogadro constant)

Note: * are the non-reactive noble gases, they do not form molecules and remain in monoatomic state, however, since molecular diffusion model is the emphasis of this paper, therefore, they have been considered as molecules too.

Table 2. Energy possessed by the gas molecules at temperature of 303 K, their recessional velocities and the distance covered by them in 1 second **(Graph 1)**

Gaseous Elements	Temperature (T) K	Energy possessed by molecule (E) J	Recessional Velocity (v) m s^{-1}	Distance covered in 1 second (D) m
H	303	6.2750 x 10^{-21}	1936.30	1936.30
He*	303	6.2750 x 10^{-21}	971.68	971.68
N	303	6.2750 x 10^{-21}	519.41	519.41
O	303	6.2750 x 10^{-21}	485.99	485.99
F	303	6.2750 x 10^{-21}	445.98	445.98
Ne*	303	6.2750 x 10^{-21}	432.73	432.73
Cl	303	6.2750 x 10^{-21}	326.48	326.48
Ar*	303	6.2750 x 10^{-21}	307.56	307.56
Kr*	303	6.2750 x 10^{-21}	212.36	212.36
Xe*	303	6.2750 x 10^{-21}	169.65	169.65
Rn*	303	6.2750 x 10^{-21}	130.46	130.46

Table 3. Energy possessed by the gas molecules at temperature of 303 K, their recessional velocity and the distance covered by them in 60 seconds **(Graph 2)**

Gaseous Elements	Temperature (T) K	Energy possessed by molecule (E) J	Recessional Velocity (v) m s^{-1}	Distance covered in 60 seconds (D) m
H	303	6.2750 x 10^{-21}	1936.30	116178.0
He*	303	6.2750 x 10^{-21}	971.68	58300.8
N	303	6.2750 x 10^{-21}	519.41	31164.6
O	303	6.2750 x 10^{-21}	485.99	29159.4
F	303	6.2750 x 10^{-21}	445.98	26758.8
Ne*	303	6.2750 x 10^{-21}	432.73	25963.8
Cl	303	6.2750 x 10^{-21}	326.48	19588.8
Ar*	303	6.2750 x 10^{-21}	307.56	18453.6
Kr*	303	6.2750 x 10^{-21}	212.36	12741.6
Xe*	303	6.2750 x 10^{-21}	169.65	10179.0
Rn*	303	6.2750 x 10^{-21}	130.46	7827.6

Table 4. Random energy possessed by the gas molecules due to random temperature, their recessional velocity and the distance covered by them in 1 second **(Graph 3)**

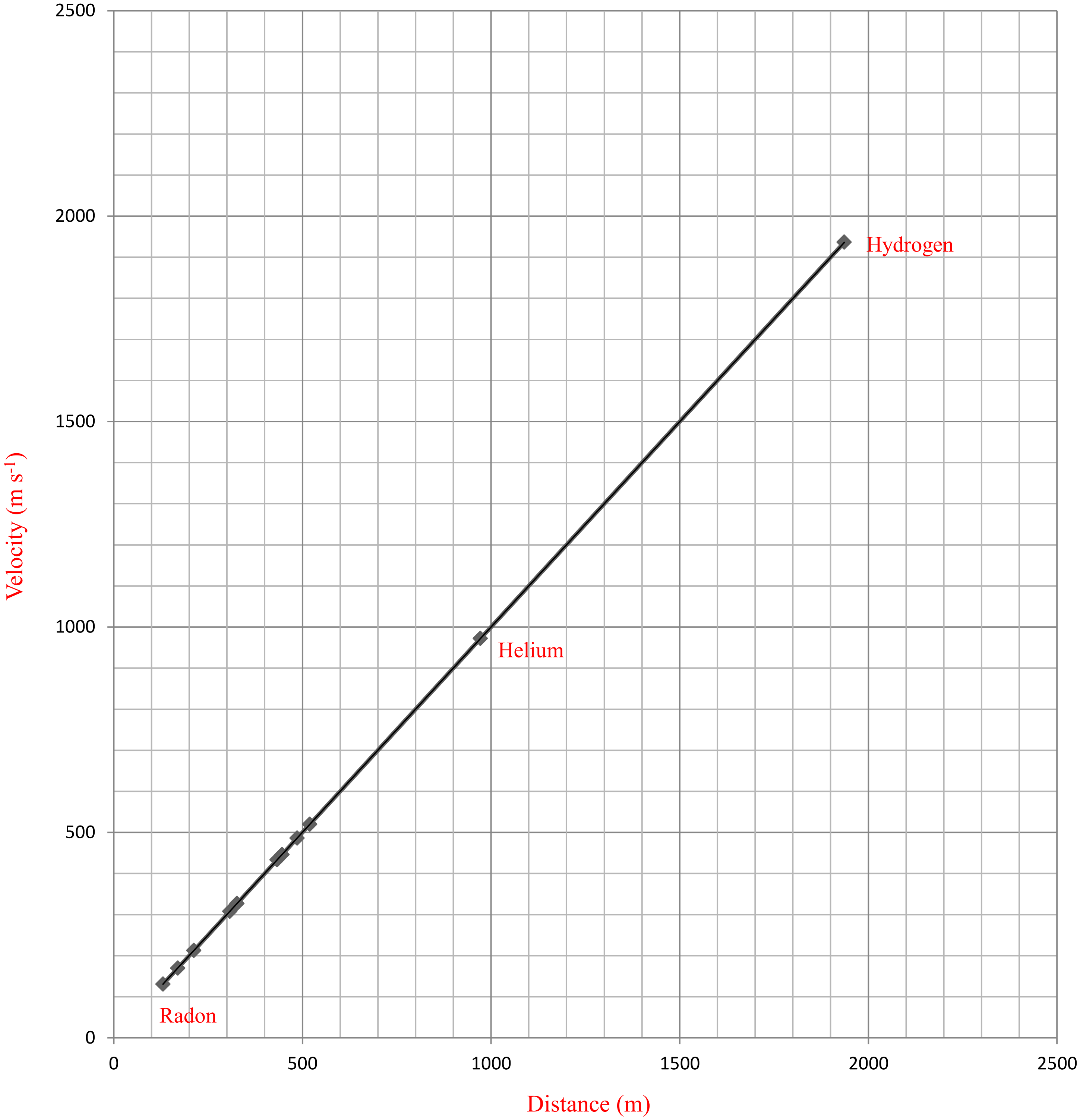
Gaseous Elements	Random Temperature (T) K	Energy possessed by molecule (E) J	Recessional Velocity (v) m s^{-1}	Distance covered in 1 second (D) m
H	306	6.3371 x 10^{-21}	1945.86	1945.86
He*	310	6.4200 x 10^{-21}	982.85	982.85
N	313	6.4821 x 10^{-21}	527.91	527.91
O	305	6.3164 x 10^{-21}	487.59	487.59
F	311	6.4407 x 10^{-21}	451.83	451.83
Ne*	303	6.2750 x 10^{-21}	432.73	432.73
Cl	308	6.3786 x 10^{-21}	329.16	329.16
Ar*	312	6.4614 x 10^{-21}	312.09	312.09
Kr*	304	6.2957 x 10^{-21}	212.71	212.71
Xe*	307	6.3578 x 10^{-21}	170.76	170.76
Rn*	309	6.3993 x 10^{-21}	131.75	131.75

Table 5. Random energy possessed by the gas molecules due to random temperature, their recessional velocity and the distance covered by them in 60 seconds **(Graph 4)**

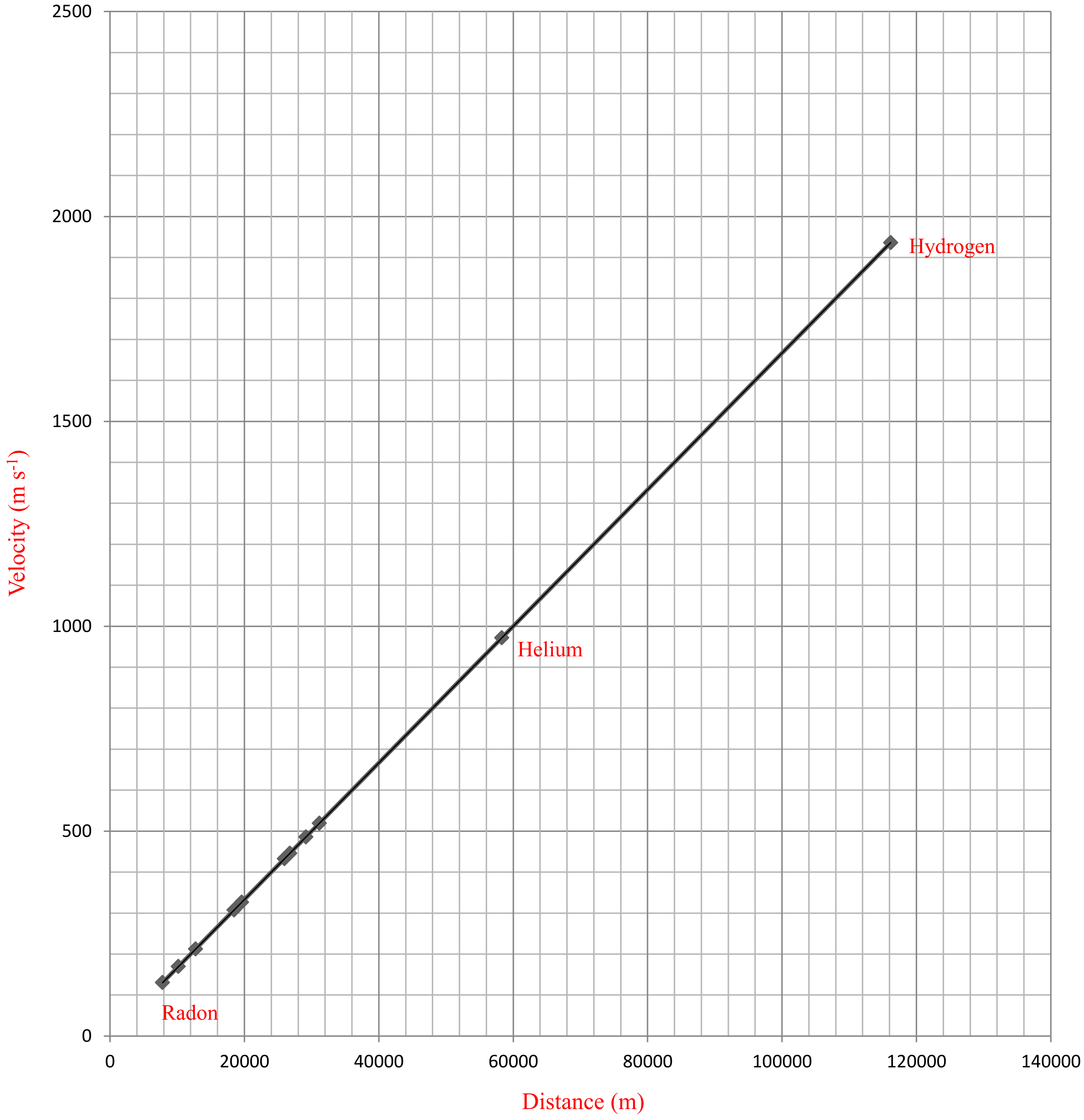
Gaseous Elements	Random Temperature (T) K	Energy possessed by molecule (E) J	Recessional Velocity (v) m s^{-1}	Distance covered in 60 seconds (D) m
H	306	6.3371×10^{-21}	1945.86	116751.6
He*	310	6.4200×10^{-21}	982.85	58971.0
N	313	6.4821×10^{-21}	527.91	31674.6
O	305	6.3164×10^{-21}	487.59	29255.4
F	311	6.4407×10^{-21}	451.83	27109.8
Ne*	303	6.2750×10^{-21}	432.73	25963.8
Cl	308	6.3786×10^{-21}	329.16	19749.6
Ar*	312	6.4614×10^{-21}	312.09	18725.4
Kr*	304	6.2957×10^{-21}	212.71	12762.6
Xe*	307	6.3578×10^{-21}	170.76	10245.6
Rn*	309	6.3993×10^{-21}	131.75	7905.0

Table 6. Random energy possessed by the gas molecules due to extreme random temperature, their recessional velocity and the distance covered by them in 60 seconds **(Graph 5)**

Gaseous Elements	Random Temperature (T) K	Energy possessed by molecule (E) J	Recessional Velocity (v) m s^{-1}	Distance covered in 60 seconds (D) m
H	1000	2.0709×10^{-20}	3517.60	211056.0
He*	2000	4.1419×10^{-20}	2496.43	149785.8
N	10000	2.0709×10^{-19}	2983.93	179035.8
O	9000	1.8638×10^{-19}	2648.64	158918.4
F	900	1.8638×10^{-20}	768.62	46117.2
Ne*	8000	1.6567×10^{-19}	2223.52	133411.2
Cl	800	1.6567×10^{-20}	530.48	31828.8
Ar*	9000	1.8638×10^{-19}	1676.20	100572.0
Kr*	10000	2.0709×10^{-19}	1219.96	73197.6
Xe*	700	1.4496×10^{-20}	257.85	15471.0
Rn*	15000	3.1064×10^{-19}	917.97	55078.2

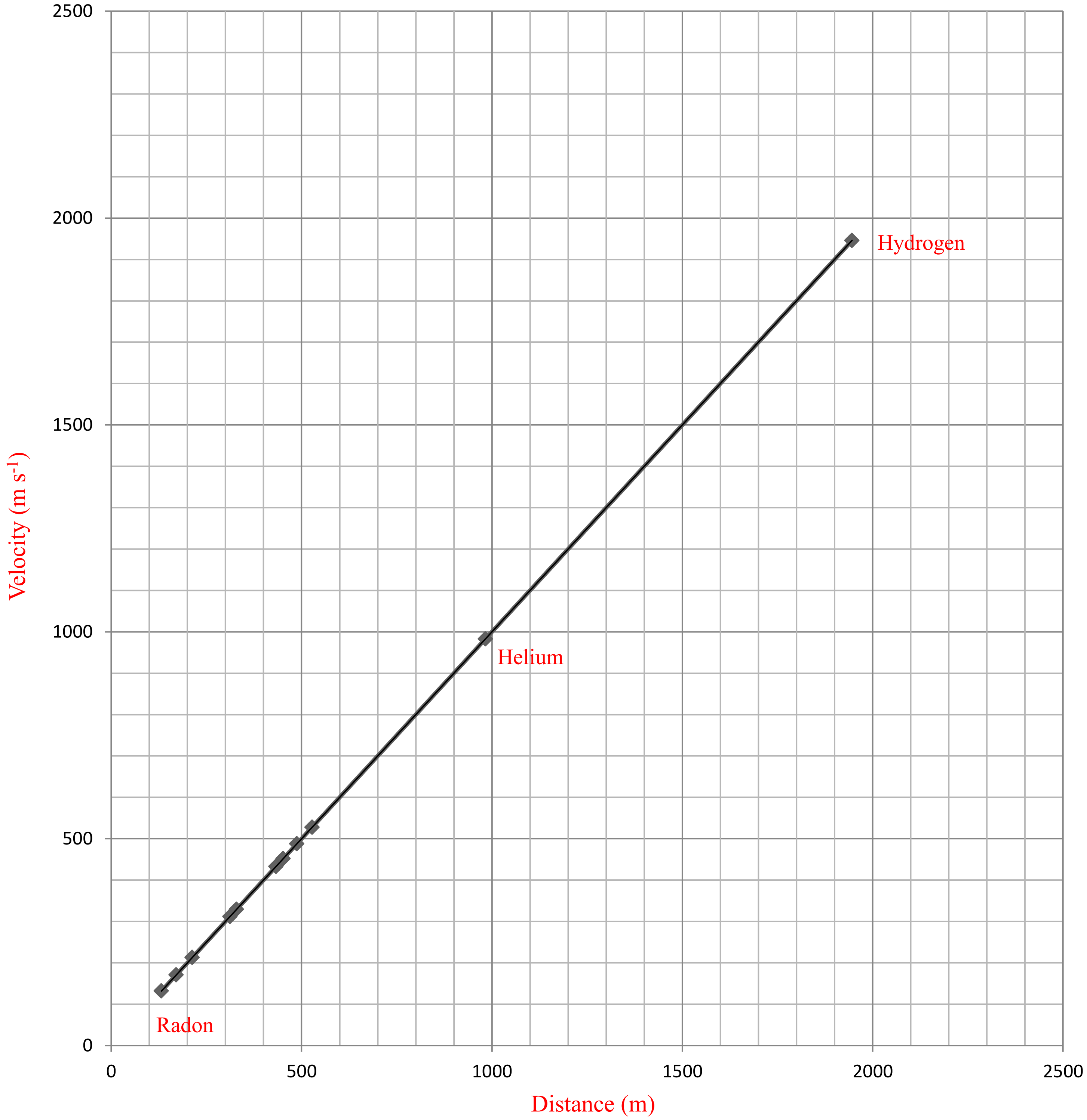


Graph 1. Velocity-distance relation plot for molecules diffusing at same temperature (303 K). Observation time = 1 second **(Table 2)** (Slope = 1 m s^{-1} m^{-1})



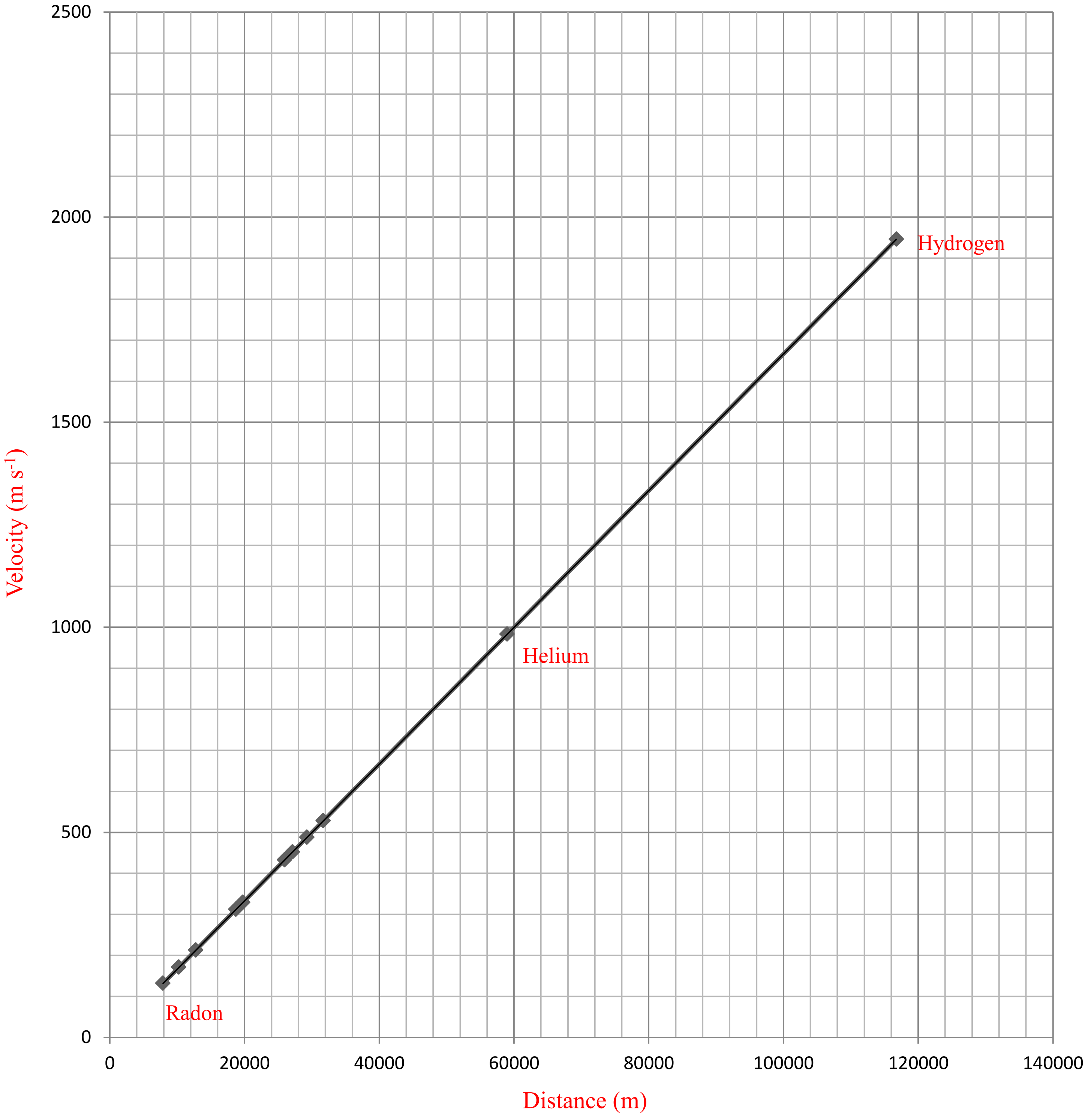
Graph 2. Velocity-distance relation plot for gas molecules diffusing at same temperature (303 K). Observation time = 60 seconds **(Table 3)**

(Slope = 0.016666666 m s^{-1} m^{-1})



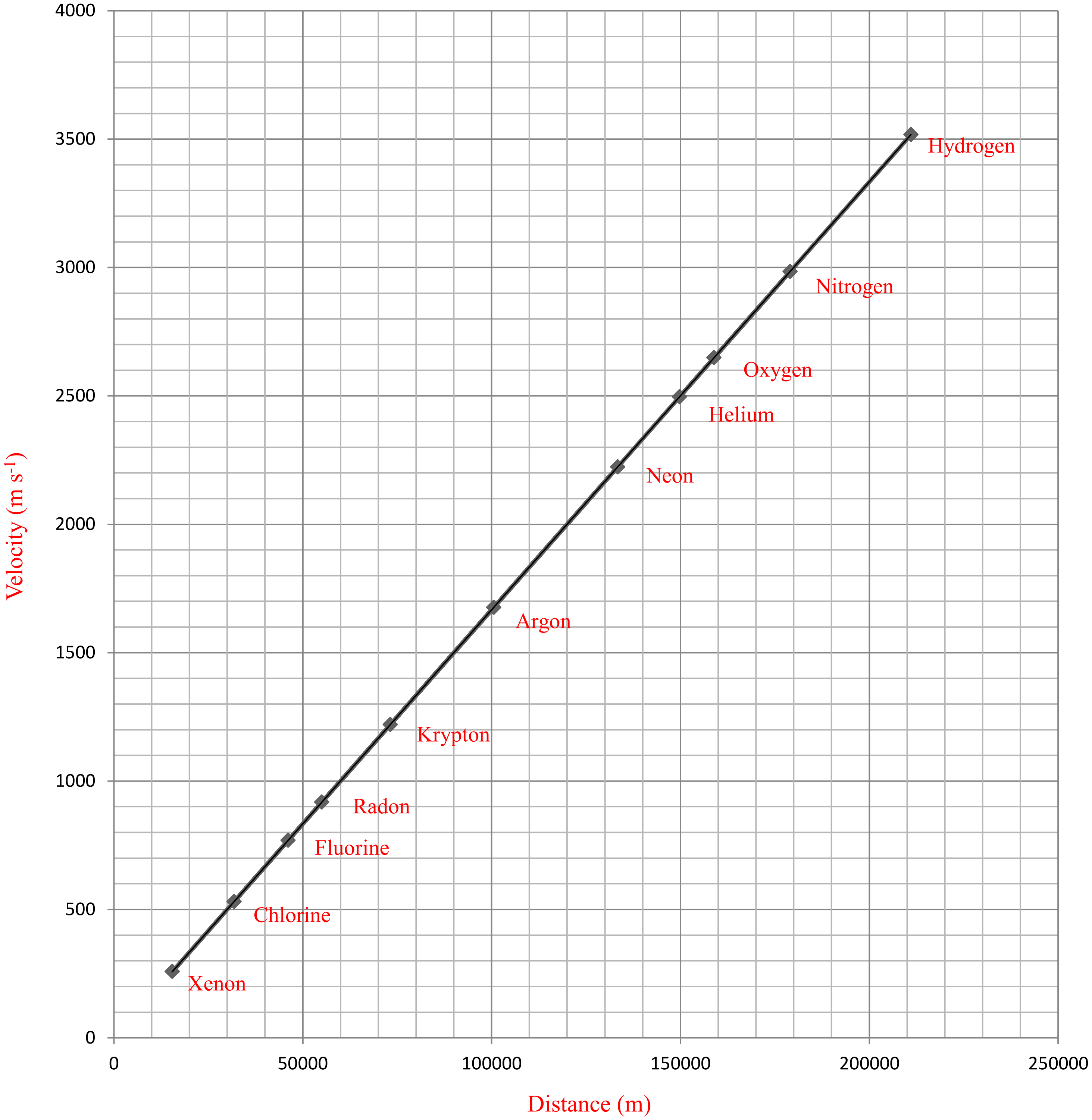
Graph 3. Velocity-distance relation plot for gas molecules diffusing at random temperature. Observation time = 1 second **(Table 4)**

(Slope = 1 m s^{-1} m^{-1})



Graph 4. Velocity-distance relation plot for gas molecules diffusing at random temperature. Observation time = 60 seconds **(Table 5)**

(Slope = 0.016666666 m s^{-1} m^{-1})



Graph 5. Velocity-distance relation plot for molecules diffusing at extreme random temperature. Observation time = 60 seconds **(Table 6)** (Slope = 0.016666666 m s^{-1} m^{-1})

Table 7. Recalculating the distance covered by molecules from the value of the Slope obtained from **Graph 1** (Slope = 1 m s^{-1} m^{-1})

(See **Table 2** to cross-check)

Recessional Velocity (v) m s^{-1}	**D = v / Slope** m
1936.30	1936.30
971.68	971.68
519.41	519.41
485.99	485.99
445.98	445.98
432.73	432.73
326.48	326.48
307.56	307.56
212.36	212.36
169.65	169.65
130.46	130.46

Table 8. Recalculating the recessional velocity of molecules from the value of the Slope obtained from **Graph 1** (Slope = 1 m s^{-1} m^{-1})

(See **Table 2** to cross-check)

Distance (D) m	**v = Slope x D** m s^{-1}
1936.30	1936.30
971.68	971.68
519.41	519.41
485.99	485.99
445.98	445.98
432.73	432.73
326.48	326.48
307.56	307.56
212.36	212.36
169.65	169.65
130.46	130.46

Table 9. Recalculating the distance covered by molecules from the value of the Slope obtained from **Graph 2** (Slope = 0.016666666 m s^{-1} m^{-1})

(See **Table 3** to cross-check)

Recessional Velocity (v) m s^{-1}	$D = v$ / **Slope** m
1936.30	116178.0
971.68	58300.8
519.41	31164.6
485.99	29159.4
445.98	26758.8
432.73	25963.8
326.48	19588.8
307.56	18453.6
212.36	12741.6
169.65	10179.0
130.46	7827.6

Table 10. Recalculating the recessional velocity of molecules from the value of the Slope obtained from **Graph 2** (Slope = 0.016666666 m s^{-1} m^{-1})

(See **Table 3** to cross-check)

Distance (D) m	v = **Slope x** D m s^{-1}
116178.0	1936.30
58300.8	971.68
31164.6	519.41
29159.4	485.99
26758.8	445.98
25963.8	432.73
19588.8	326.48
18453.6	307.56
12741.6	212.36
10179.0	169.65
7827.6	130.46

Table 11. Recalculating the distance covered by molecules from the value of the Slope obtained from **Graph 3** (Slope = 1 m s^{-1} m^{-1})

(See **Table 4** to cross-check)

Recessional Velocity (v) m s^{-1}	$D = v$ / **Slope** m
1945.86	1945.86
982.85	982.85
527.91	527.91
487.59	487.59
451.83	451.83
432.73	432.73
329.16	329.16
312.09	312.09
212.71	212.71
170.76	170.76
131.75	131.75

Table 12. Recalculating the recessional velocity of molecules from the value of the Slope obtained from **Graph 3** (Slope = 1 m s^{-1} m^{-1})

(See **Table 4** to cross-check)

Distance (D) m	v = **Slope x** D m s^{-1}
1945.86	1945.86
982.85	982.85
527.91	527.91
487.59	487.59
451.83	451.83
432.73	432.73
329.16	329.16
312.09	312.09
212.71	212.71
170.76	170.76
131.75	131.75

Table 13. Recalculating the distance covered by molecules from the value of the Slope obtained from **Graph 4** (Slope = 0.016666666 m s^{-1} m^{-1})

(See **Table 5** to cross-check)

Recessional Velocity (v) m s^{-1}	***D*** **=** v **/ Slope** m
1945.86	116751.6
982.85	58971.0
527.91	31674.6
487.59	29255.4
451.83	27109.8
432.73	25963.8
329.16	19749.6
312.09	18725.4
212.71	12762.6
170.76	10245.6
131.75	7905.0

Table 14. Recalculating the recessional velocity of molecules from the value of the Slope obtained from **Graph 4** (Slope = 0.016666666 m s^{-1} m^{-1})

(See **Table 5** to cross-check)

Distance (D) m	v **= Slope x** ***D*** m s^{-1}
116751.6	1945.86
58971.0	982.85
31674.6	527.91
29255.4	487.59
27109.8	451.83
25963.8	432.73
19749.6	329.16
18725.4	312.09
12762.6	212.71
10245.6	170.76
7905.0	131.75

Table 15. Recalculating the distance covered by molecules from the value of the Slope obtained from **Graph 5** (Slope = 0.016666666 m s^{-1} m^{-1})

(See **Table 6** to cross-check)

Recessional Velocity (v) m s^{-1}	$D = v$ / **Slope** m
3517.60	211056.0
2496.43	149785.8
2983.93	179035.8
2648.64	158918.4
768.62	46117.2
2223.52	133411.2
530.48	31828.8
1676.20	100572.0
1219.96	73197.6
257.85	15471.0
917.97	55078.2

Table 16. Recalculating the recessional velocity of molecules from the value of the Slope obtained from **Graph 5** (Slope = 0.016666666 m s^{-1} m^{-1})

(See **Table 6** to cross-check)

Distance (D) m	v = **Slope x** D m s^{-1}
211056.0	3517.60
149785.8	2496.43
179035.8	2983.93
158918.4	2648.64
46117.2	768.62
133411.2	2223.52
31828.8	530.48
100572.0	1676.20
73197.6	1219.96
15471.0	257.85
55078.2	917.97

CONCLUSIONS

(1) In this paper the real meaning of the Hubble diagram has been unravelled based upon the detailed study conducted on the basis of the molecular diffusion model.

(2) The molecular diffusion model considers the distribution of large-scale structures as molecules. If the molecular diffusion model is valid for the receding large-scale structures, then there should be certain properties of receding large-scale structures that should match with the properties of receding gas molecules.

(3) According to the molecular diffusion model the distance between the large-scale structures is increasing due to their actual recession by the virtue of the energy possessed by them.

(4) Large-scale structures recede with velocity corresponding to the total amount of energy that they possess.

(5) For a large-scale structure to exhibit higher recessional velocity the energy possessed by it should be sufficiently large and the mass should be less.

(6) The highest recessional velocities are always found to be exhibited by the most distant galaxies and not by galaxy clusters. This observation is consistent with the recessional behaviour of molecules, that is, a lighter molecule exhibits higher recessional velocity as compared to a massive molecule even when they both possess an equivalent amount of energy. Such consistent recessional behaviour suggests the actual recession of large-scale structures rather than expansion of space between them.

(7) Since galaxies are less massive as compared to galaxy clusters, therefore, galaxies exhibit higher recessional velocities comparatively, and for this reason, galaxies become the most distant structures within the observable Universe.

(8) From the tables and the graphs it becomes very evident that the behaviour of receding large-scale structures is similar to the behaviour of diffusing or free expanding gas molecules inside a vacuum chamber. The velocity-distance relation plot for diffusing gas molecules is consistent with the velocity-distance relation plot for the receding large-scale structures obtained according to the Hubble diagram which depicts the Hubble's law. Such consistency also suggests the actual recession of large-scale structures rather than expansion of space between them; if the space between the large-scale structures was expanding, then the velocity-distance relation plot for the receding large-scale structures and the receding gas molecules would have been completely different from one another.

(9) The first four molecular plots are exactly like the Hubble diagram; the molecules receding slowly (molecules that are closer to us) get plotted close to one another as compared to the molecules that exhibit higher recessional velocity (molecules that are further away from us). Also, nearby molecules are massive as compared to the distant molecules. The distribution of molecules in the fifth molecular plot is different due to large differences (randomness) in temperature and energy possessed by the molecules. Randomness has been deliberately introduced to see if the molecules deviate from exhibiting a linear velocity-distance relation.

(10) No matter how randomly the data changes for the gas molecules, the velocity-distance relation plots continue to exhibit the highly linear behaviour just like the Hubble diagram.

(11) The value of the Slope obtained from the velocity-distance relation plot for the diffusing gas molecules is similar to the Hubble constant (H) (the slope of Hubble diagram), since its reciprocal gives us the observation time in seconds, just like the Hubble time obtained from the reciprocal of (H).

(12) From the velocity-distance relation plot for the gas molecules it is found that the further away a gas molecule is, the faster it will be receding away from us, that is, the recessional velocity of gas molecules is directly proportional to their distance. This is also consistent with the Hubble's law.

(13) The Hubble's law and all Hubble equations are found to be obeyed by the receding gas molecules as well, equations like $v = H \times D$, $D = v/H$, $t_H = 1/H$; where v is the recessional velocity, H is the Hubble constant, D is the distance and t_H is the Hubble time. For gas molecules the corresponding equations are v = Slope x D, $D = v/$Slope, t = 1/Slope.

(14) No matter on which molecule we are situated upon, all molecules will exhibit redshift. This observation is consistent with the receding large-scale structures since all receding large-scale structures exhibit redshift except for some exceptionally rare ones.

(15) By knowing the values of the Slope and the distance covered by the receding gas molecules, their recessional velocity can be recalculated. Similarly, by knowing the values of the Slope and the recessional velocity of gas molecules, the distance covered by them can be recalculated. This is again consistent with the Hubble diagram.

(16) Since gas molecules exhibit Hubble diagram and obey all Hubble equations solely due to their recession by the virtue of the energy possessed by them, therefore, the large-scale structures that are known to exhibit Hubble diagram and obey all Hubble equations have to be receding solely by the virtue of the energy possessed by them.

(17) The gas molecules and the large-scale structures get segregated in terms of velocity and distance according to their mass and the energy possessed by them.

(18) Plotting the velocity-distance relation for the receding large-scale structures is same as plotting the velocity-distance relation for diffusing gas molecules.

(19) Receding gas molecules will always exhibit Hubble-diagram. Since receding large-scale structures behave like receding gas molecules; justified by identical velocity-distance relation plots, the Hubble diagram therefore simply is the velocity-distance relation plot for receding gas molecules.

(20) The similarities encountered while plotting the velocity-distance relation plots for the receding large-scale structures and the receding gas molecules validate the credibility of the molecular diffusion model.

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