UNIVERSE WITHOUT DARK ENERGY

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

ABSTRACT

The value of the cosmological constant obtained according to the quantum field theory is 10^{120} times greater than the observed small value of the cosmological constant. Such huge discrepancy with the cosmological constant would cause a vacuum catastrophe. Since the discrepancy involved with the cosmological constant is unimaginably very large, therefore, molecular diffusion model has been introduced in this paper as an alternative to dark energy in order to explain the accelerated 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. Since the discrepancy involved with the cosmological constant is very large, therefore, instead of considering that empty space possesses energy, it would be much more prudent to consider that large-scale structures possess energy by the virtue of which they recede, quite similar to a molecule that recedes by the virtue of energy that it possesses, after all, "the diffusion or free expansion of gas molecules inside a vacuum chamber by the virtue of vacuum energy or dark energy" has never been heard of; such claim, if true, would only suggest that gas molecules do not possess any energy. The study conducted in this paper finds the recessional behaviour of large-scale structures to be consistent with the recessional behaviour of molecules, thereby proving the molecular diffusion model.

Key words: cosmology: theory - dark energy.

1 INTRODUCTION

The Universe astonishes us all as it continues to expand at an accelerating rate instead of coming to a halt or even slowing down. A mysterious energy rightfully termed as dark energy is considered responsible for this accelerated expansion. Dark energy introduced itself 5 billion years ago (Frieman, Turner and Huterer 2008) and since then the Universe has continued to expand at an accelerating rate; before this time the expansion of the Universe was decelerating due to the gravitational attraction of matter. The accelerating expansion of the Universe was discovered independently by the High-Z Supernova Search Team in the 1998 (Riess et al.) and by Supernova Cosmology Project team in the 1999 (Perlmutter et al.) by measuring the distance to Type Ia supernovae from their brightness (standard candles) and then comparing this distance with the supernovae's cosmological redshift. Dark energy occupies the entire Universe just like the Cosmic Microwave Background Radiation (CMBR), but unlike the CMBR whose energy density decreases with time as the Universe expands, the energy density of dark energy remains constant.

"Up to date our single indication for the existence of dark energy comes from distance measurements and their relation to redshift" (Durrer 2011). There are many theories that try to tackle the dark energy problem. What type of energy it exactly is remains an unsolved mystery; dark energy is hypothetical.

In 1917, Sir Albert Einstein had introduced a special term into his gravitational equation to account for a "static" Universe; a Universe that neither contracts nor expands; the average distance between the celestial objects remains same in a static Universe. The special term was the cosmological constant, denoted by Λ. This constant was introduced to overcome the gravitational attraction of matter that tends to contract and collapse the Universe. The fate of the Universe depends upon whether the cosmological constant is positive or negative. If positive, then gravitational repulsion or expansion is assured, and, if negative, then gravitational attraction or contraction would become inevitable.

In 1929, Sir Edwin Hubble gathered vital data from his observations of distant galaxies from Mount Wilson Observatory in California that proved that the Universe is expanding and is not static at all as was previously considered. The redshifts of the observed galaxies suggested that the distance between the galaxies was increasing, indicating that the galaxies were receding away from each other. This observation of expanding Universe against the idea of static Universe led to the abandoning of the cosmological constant idea.

Surprisingly, the independent observations of the distant Type Ia supernovae in 1998 and 1999 revealed that the Universe is not only expanding, but that expansion was accelerating. This observation made it imperative to bring back the discarded cosmological constant once again. In the simplest form, the cosmological constant is equivalent to the energy density of empty space or vacuum (vacuum energy density). However, when the value of the cosmological constant is obtained according to the quantum field theory, a huge discrepancy is introduced. Quantum field theory provides the theoretical value of the cosmological constant to be extremely large (~ 2 x 10^{110} erg cm^{-3}) as compared to the observed value of the cosmological constant which is extremely small (~ 2 x 10^{-10} erg cm^{-3}) (Carroll 2001). The theoretically obtained value of the cosmological constant according to the quantum field theory is 10^{120} times greater than the observed small value of the cosmological constant. Such discrepant problem with the cosmological constant would lead to a vacuum catastrophe.

The aim of this paper is to explain the accelerated expansion of the Universe by considering the molecular diffusion model which has been introduced in Section 2. In Section 3 the recessional behaviour of large-scale structures is found to be consistent with the recessional behaviour of molecules, thereby suggesting their actual recession. In Section 4 I discuss that the observed redshifts exhibited by large-scale structures are due to their actual recession. Section 5 suggests that the large-scale structures will attain a constant recessional velocity in distant future. In Section 6 I show that the energy possessed by the receding large-scale structures is greater than the gravitational influence between them. Section 7 incorporates the mass-energy relation as an additional proof to support the molecular diffusion model. Section 8 briefly discusses the fate of the Universe, while Section 9 brings actual gas molecules into consideration to further study and compare the recessional behaviour of large-scale structures with gas molecules.

2 MOLECULAR DIFFUSION MODEL

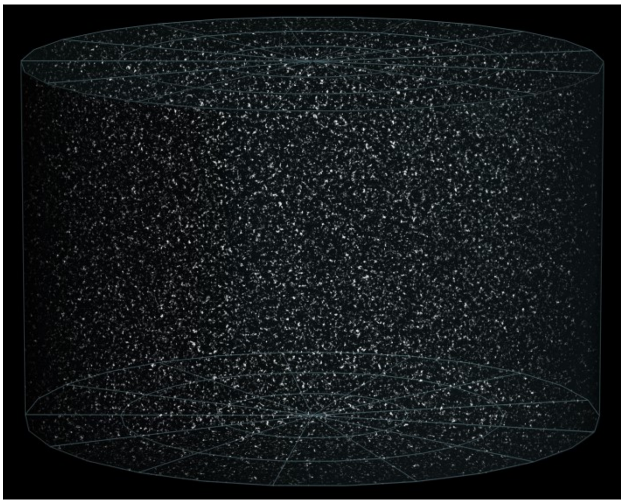


Figure 1. Large-scale structures within the observable Universe. When compared to the infinite volume of the Universe, the large-scale structures can be considered as molecules inside a vacuum chamber. The large-scale structures possess finite amount of energy by the virtue of which they diffuse or recede (expand freely) into the empty space just like molecules that diffuse or expand freely in an ultra-high vacuum chamber by the virtue of the energy that they possess. Since large-scale structures possess finite amount of energy, therefore, their recessional velocity must become constant in the distant future instead of increasing forever.

Diffusion is the flow of molecules from the region of their higher concentration to the region of lower concentration in the presence of a gradient which can be a concentration gradient, a pressure gradient, a thermal gradient or a combination of these. The celestial objects distributed within the observable Universe are concentrated within the observable Universe, therefore, they must diffuse from the region of their higher concentration to the region of lower concentration, that is, from the observable Universe to the region beyond the observable Universe.

As shown in Figure 1, all large-scale structures (galaxies, galaxy clusters, superclusters, etc.) when compared to the gigantic volume of the infinite Universe, resemble microscopic particles, almost like gas molecules in an infinite and ultra-high vacuum chamber. Therefore, instead of maintaining a fixed position within the Universe, the large-scale structures would most probably prefer to diffuse out or expand freely into the infinite realm by the virtue of the diffusion energy that they possess, after all, diffusion or recession of a molecule occurs due to the energy it possesses.

Accelerated recession of large-scale structures as observed is only possible if the receding large-scale structures are still in the process of attaining a constant recessional velocity corresponding to the finite amount of energy possessed by them; just like an object that keeps accelerating before attaining a constant velocity; the velocity keeps increasing every second as long as the permissible constant velocity is not attained. Increasing distance between the large-scale structures due to their recession away from each other causes the gravitational force between them to weaken, while their recessional velocity would keep on increasing before becoming constant in distant future.

Gravity being the only force between the distant large-scale structures is not strong enough to retard the recession because the diffusion or the recessional energy possessed by the receding large-scale structures is greater than the mutual gravitational force between them (Section 6).

A large-scale structure such as a galaxy cluster harbours more atoms throughout its volume. When compared to the colossal size of the infinite Universe we can consider such large-scale structure as a single molecule since it is an ensemble of many atoms all bound gravitationally; such structure possesses finite amount of energy and therefore it recedes as a single molecule.

In case of molecules which are just about to diffuse or expand freely inside a vacuum chamber, if the attractive force between the molecules is increased somehow, then such attractive force will out power the energy that causes the molecules to diffuse, in such case the molecules would remain clumped together instead of diffusing or expanding freely inside the vacuum chamber. The attractive force between molecules is analogous to gravity between the structures. The structures that cause its constituents to orbit around are bound strongly by gravity, and the diffusing ability is out powered by such gravitational force (star causes planets to orbit around it, galaxy causes stars and gas clouds to orbit around it, and, galaxy cluster causes galaxies to orbit around it). Therefore, planets do not diffuse or recede out of a planetary system, stars do not diffuse out of a galaxy, and galaxies do not diffuse out of the cluster; such structures do not expand. On the other hand, the gravitationally self-bound large-scale structures which do not seem to orbit around any other large-scale structures (suggesting that they are not bound strongly by mutual gravitation) are able to out power the mutual gravitational force with the energy that they possess required for diffusion or recession, and therefore they diffuse or recede; structures such as galaxy clusters, field galaxies and superclusters.

Therefore, the diffusion or the recession of large-scale structures works effectively and efficiently for those structures that are separated by large distances; between field galaxies, between galaxy clusters and between superclusters. And, not within planetary systems, within galaxies and within galaxy clusters as these are gravitationally bound systems. Within gravitationally bound systems such as planetary systems, galaxies and galaxy clusters, the diffusion process is out powered by the gravitational force which is responsible for binding such systems; the gravitational force within such bound systems is more than the energy required for diffusion or recession. Therefore, we have the distance between galaxy clusters, field galaxies and superclusters increasing continuously, whereas the distance between stars in galaxies, galaxies within galaxy clusters and between planets and the central star in case of planetary systems remains unchanged.

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,

$$E = \frac{1}{2}mv^2 \tag{1}$$

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

$$v = \sqrt{\frac{2E}{m}} \tag{2}$$

Equation (2) suggests that an object possessing sufficient amount of energy will also possess velocity and therefore the object will recede. 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, 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 the gravitational influence is significantly weaker; particularly between the large-scale structures that are separated by large distances. Therefore, the energy possessed by a large-scale structure will make it recede, just like a molecule, as the energy required for recession is greater than the gravitational influence between the receding large-scale structures.

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.

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. 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. The recessional behaviour of large-scale structures being consistent with the recessional behaviour of molecules suggests the actual recession of large-scale structures.

4 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 at an accelerating rate, that is, the space between the structures is expanding at an accelerating rate 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 space is stationary and the large-scale structures are 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.

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.

The next section suggests that the receding large-scale structures will attain a constant recessional velocity in distant future due to the finite amount of energy possessed by them.

5 ACCELERATED EXPANSION OF THE UNIVERSE WILL NOT CONTINUE FOREVER: WHAT WOULD BE THE FINAL RECESSIONAL VELOCITY THEN ?

Large-scale structures recede by the virtue of energy possessed by them, instead of energy being possessed by empty space. Since large-scale structures possess finite amount of energy, therefore, their recessional velocity must get rendered constant in distant future, instead of increasing continuously forever. Accelerated recession of large-scale structures as observed is only possible if the receding large-scale structures are still within the accelerating phase, that is, they are still in the process of attaining a constant recessional velocity corresponding to the finite amount of energy possessed by them as discussed in Section 2.

As an example consider a baryonic 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}.

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

$$E = \frac{3}{2}kT \tag{3}$$

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 structure that is causing it to recede.

6 ENERGY POSSESSED BY RECEDING LARGE-SCALE STRUCTURES IS GREATER THAN THE GRAVITATIONAL INFLUENCE BETWEEN THEM

Consider a system of two identical galaxy clusters, both are equally massive (2 x 10^{15} $M_\odot$ (4 x 10^{45} kg)), and both are dominated by the ICM at temperature of 10^8 K, therefore the energy possessed by each galaxy cluster is 4.9523 x 10^{57} J (Section 5). These galaxy clusters are separated by a distance of 50 Mpc (1.5428 x 10^{24} m); typical distance between galaxy clusters. Now, since we are equating the energy possessed by the galaxy clusters with the gravitational influence between them, therefore, the result would be deemed more justified if we consider the gravitational binding energy of the system.

If the recessional energy possessed by the galaxy clusters that makes them recede is greater than the gravitational binding energy of the system, then the galaxy clusters would recede away from each other instead of remaining gravitationally bound. Since distant galaxy clusters recede away from each other instead of orbiting around one another, therefore, the gravitational binding energy of the system must be given as,

$$G.B.E. = \frac{GM_1M_2}{d} \tag{4}$$

where M_1 and M_2 are the masses of the galaxy clusters and d is the distance between them.

The gravitational binding energy of the system is found to be 6.9204 x 10^{56} J. The recessional energy, or the energy possessed by the galaxy clusters required to recede is 7.15 times greater than the gravitational binding energy of the system, therefore, instead of remaining gravitationally bound to each other, the galaxy clusters would diffuse or recede away from each other into the cosmic wilderness.

7 USING MASS-ENERGY RELATION AS AN ADDITIONAL PROOF TO SUPPORT THE MOLECULAR DIFFUSION MODEL

The mass of ordinary matter within the observable Universe is 10^{53} kg (Davies 2006). The diameter of the observable Universe is 8.8 x 10^{26} m (Bars and Terning 2009). The volume of the observable Universe therefore equates to 3.5681 x 10^{80} m^3.

According to Planck 2013 results, baryonic matter, dark matter and dark energy make 4.9 %, 26.8 % and 68.3 % of the Universe respectively. Since 10^{53} kg of matter accounts for 4.9 % of ordinary (baryonic) matter within the observable Universe, therefore, total matter content at 31.7 % should equate to 6.4693 x 10^{53} kg; this yields a matter density of 1.8130 x 10^{-27} kg m^{-3}.

Using Sir Albert Einstein's mass-energy relation, $E = mc^2$, the energy equivalent to this mass turns out to be 5.8223 x 10^{70} J, and, the energy density equates to 1.6317 x 10^{-10} J m^{-3}.

Now, the dark energy density is 5.96 x 10^{-27} kg m^{-3} (Planck 2015 results). This is about 2.1265 x 10^{54} kg, that is, 1.9138 x 10^{71} J. This yields an energy density of 5.3636 x 10^{-10} J m^{-3}.

It can be seen that the values obtained for dark energy surprisingly match with the corresponding values obtained for matter. Such coincidence not only solves the discrepant problem involving 120 orders of magnitude mismatch, it also suggests that the energy is possessed by matter instead of energy being possessed by empty space.

8 FATE OF THE UNIVERSE

The Cosmic Microwave Background Radiation (CMBR) corresponds to a temperature of 2.7260 ± 0.0013 K (Fixsen 2009). The temperature of surrounding space is therefore extremely low (-270.424°C). Surrounding space at such low temperature would act like an efficient heat sink. The large-scale structures that are receding by the virtue of energy possessed by them will become energy deficient in distant future, causing them to gradually slow down and stop. Gravity will take over and the inward collapse of matter will begin.

9 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).

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 therefore be random, the observation time has been set at 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 2) which is also the velocity-distance relation plot for the receding large-scale structures. According to Hubble's law, the recessional velocity of a receding 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,

$$v = H \text{ x } D \tag{5}$$

and,

$$D = \frac{v}{H} \tag{6}$$

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 and Graph 5, the highest recessional velocity is still 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 influences the energy possessed by the molecules, thereby affecting their recessional velocities too. No matter how the data changes for the gas molecules, the graphs 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. Furthermore, the equations,

$$v = Slope \text{ x } D \tag{7}$$

and,

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

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 gas molecules, therefore, the molecular diffusion model holds good for the receding large-scale structures. The large-scale structures are therefore receding just like gas molecules by the virtue of the energy that they possess and not by the virtue of the energy of empty space.

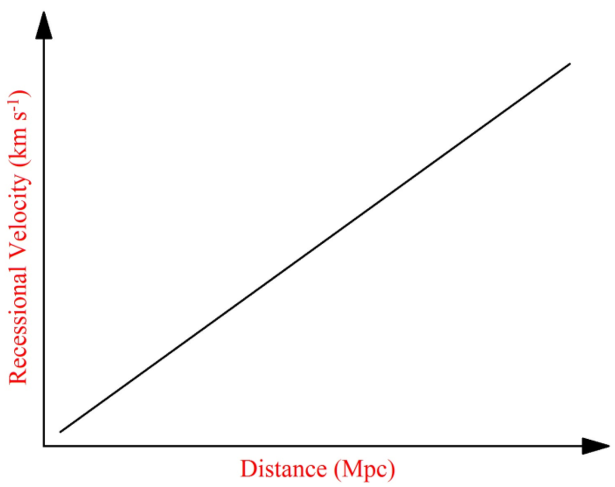


Figure 2. The Hubble diagram. Velocity-distance relation plot for receding large-scale structures. The slope of the straight line is the Hubble constant (H). The reciprocal of the Hubble constant (H) gives us the age of the Universe (Hubble time). The Hubble diagram depicts the Hubble's law according to which the recessional velocity of receding large-scale structures is directly proportional to their distance.

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/NA)/1000 kg
H	1.0079	2.0158	3.3473 x 10^{-27}
He*	4.0026	8.0052	1.3292 x 10^{-26}
N	14.0067	28.0134	4.6517 x 10^{-26}
O	15.9994	31.9988	5.3135 x 10^{-26}
F	18.9984	37.9968	6.3095 x 10^{-26}
Ne*	20.1797	40.3594	6.7018 x 10^{-26}
Cl	35.4530	70.9060	1.1774 x 10^{-25}
Ar*	39.9480	79.8960	1.3267 x 10^{-25}
Kr*	83.7980	167.5960	2.7829 x 10^{-25}
Xe*	131.2930	262.5860	4.3603 x 10^{-25}
Rn*	222.0000	444.0000	1.4745 x 10^{-24}

NA = 6.02214199 x 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}	92.25	92.25

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}	92.25	5535.0

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)**

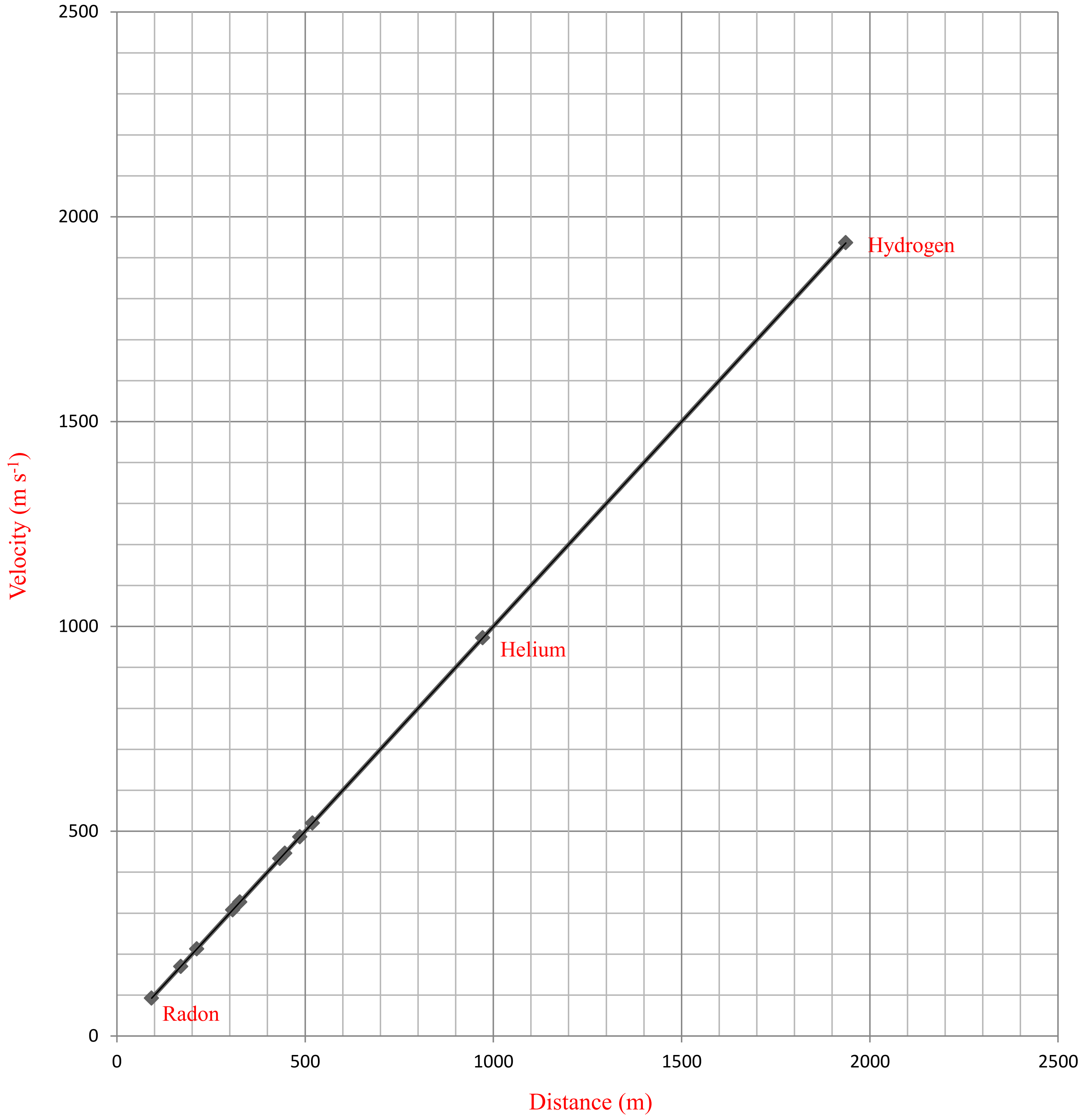
Gaseous Elements	Random Temperature (T) K	Energy possessed by molecule (E) J	Recessional Velocity (v) m s^{-1}	Distance covered in 1 second (D) m
H	306	6.3371×10^{-21}	1945.86	1945.86
He*	310	6.4200×10^{-21}	982.85	982.85
N	313	6.4821×10^{-21}	527.91	527.91
O	305	6.3164×10^{-21}	487.59	487.59
F	311	6.4407×10^{-21}	451.83	451.83
Ne*	303	6.2750×10^{-21}	432.73	432.73
Cl	308	6.3786×10^{-21}	329.16	329.16
Ar*	312	6.4614×10^{-21}	312.09	312.09
Kr*	304	6.2957×10^{-21}	212.71	212.71
Xe*	307	6.3578×10^{-21}	170.76	170.76
Rn*	309	6.3993×10^{-21}	93.16	93.16

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}	93.16	5589.6

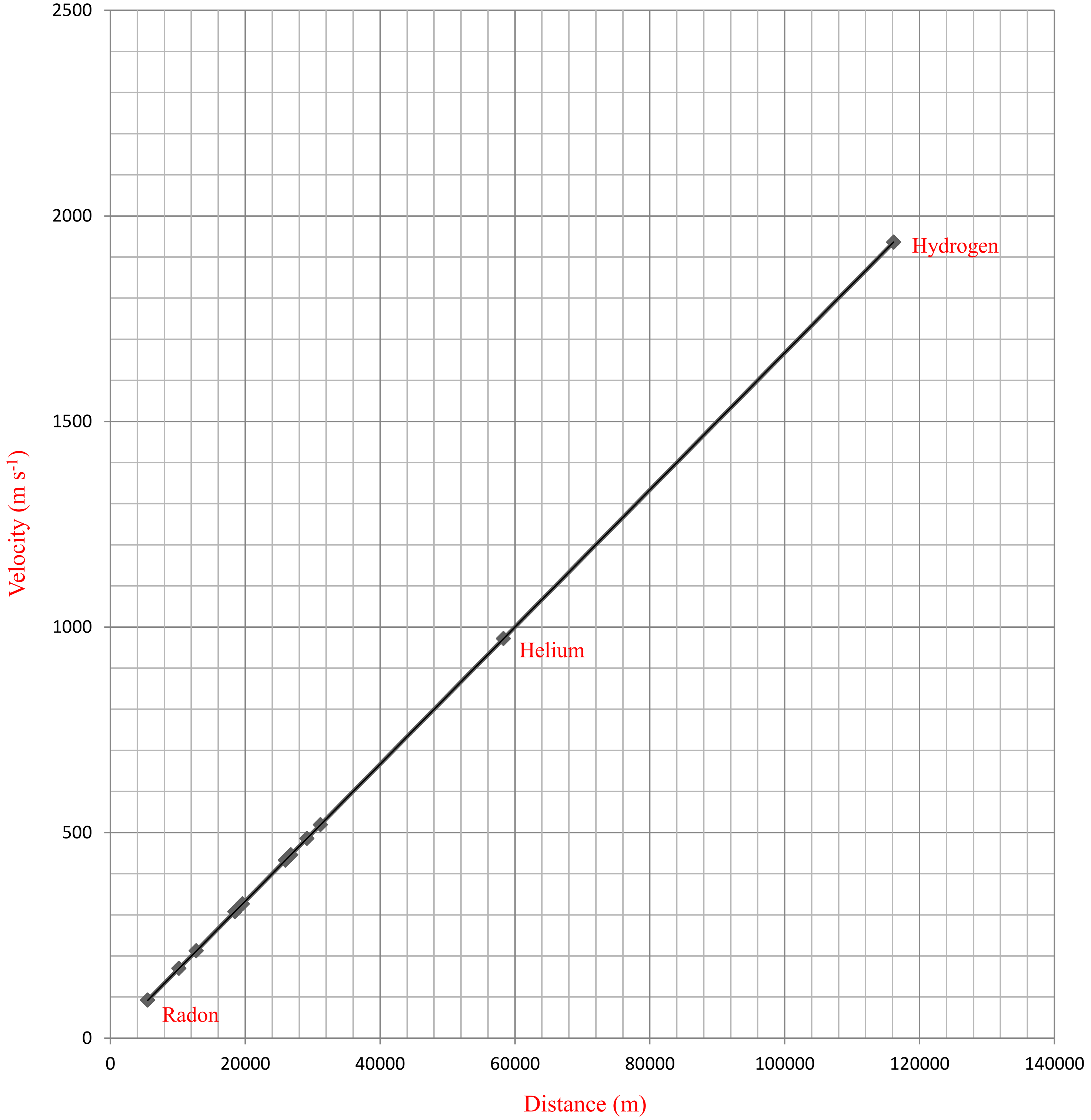
Table 6. Random energy possessed by the gas molecules due to extreme random temperature, their recessional velocity and the distance covered by them in 60 seconds **(Graph 5)**

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}	649.11	38946.6



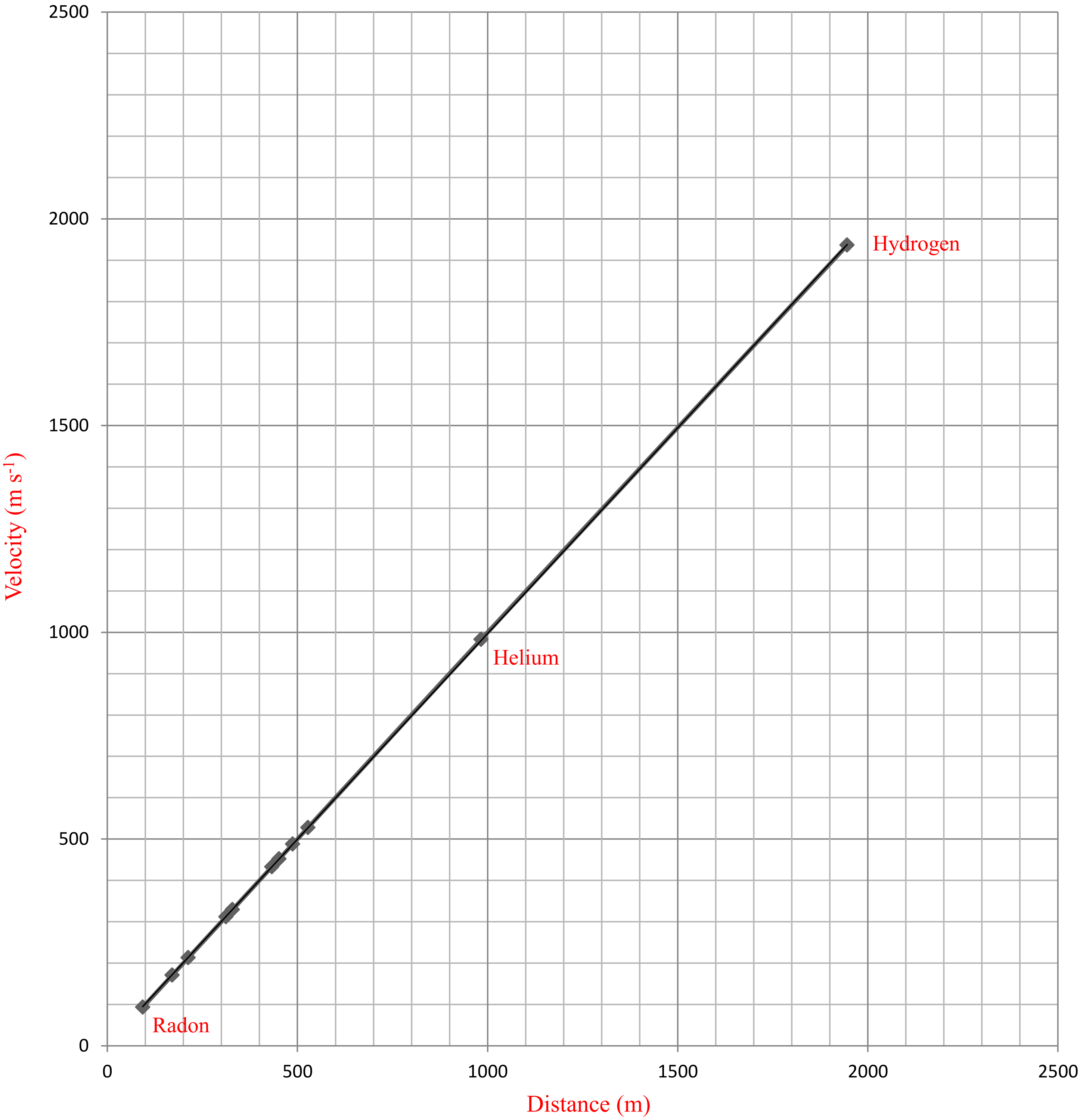
Graph 1. Velocity-distance relation plot for molecules diffusing at same temperature (303 K). Observation time = 1 second **(Table 2)**

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



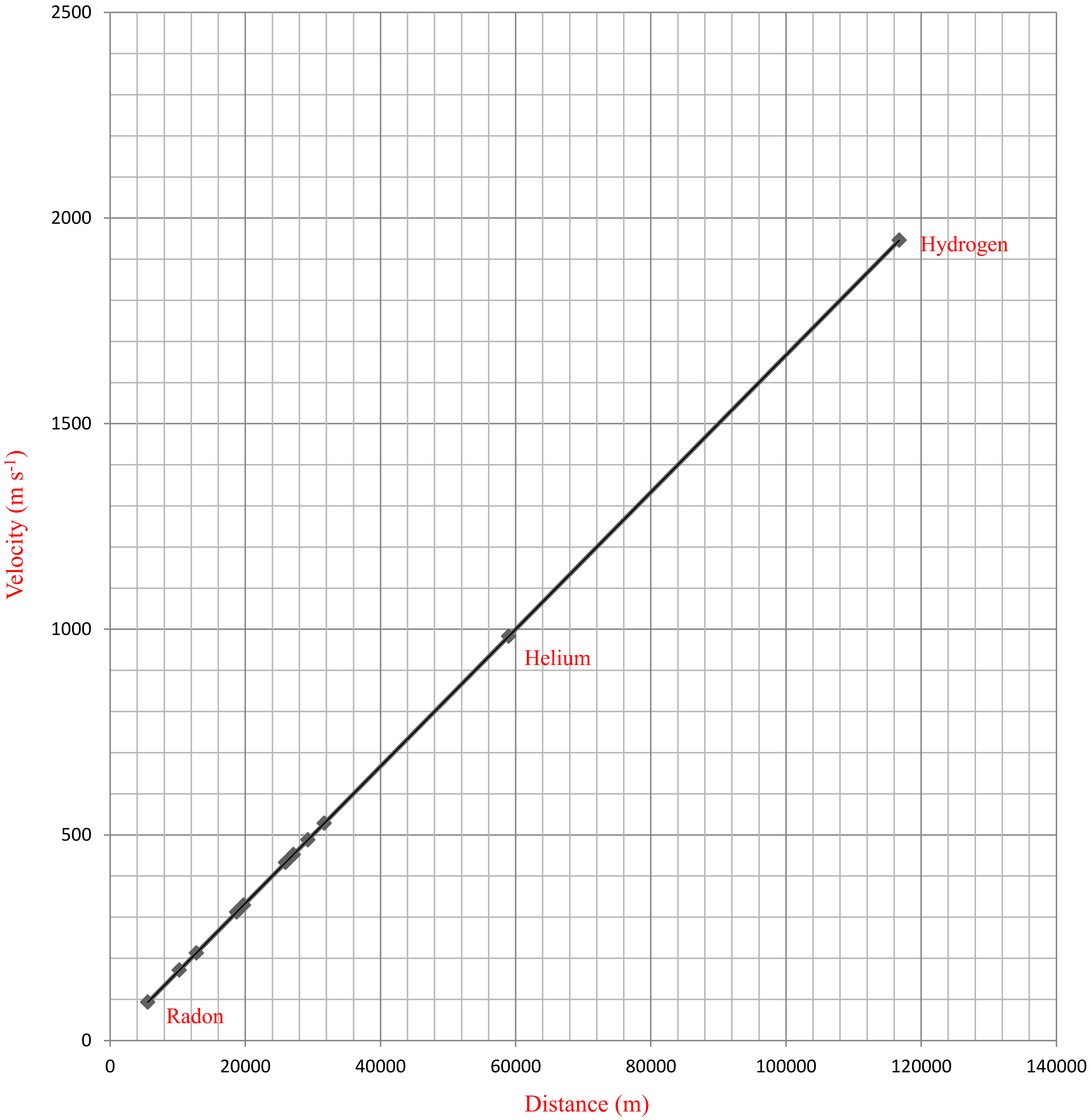
Graph 2. Velocity-distance relation plot for gas molecules diffusing at same temperature (303 K). Observation time = 60 seconds **(Table 3)**

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



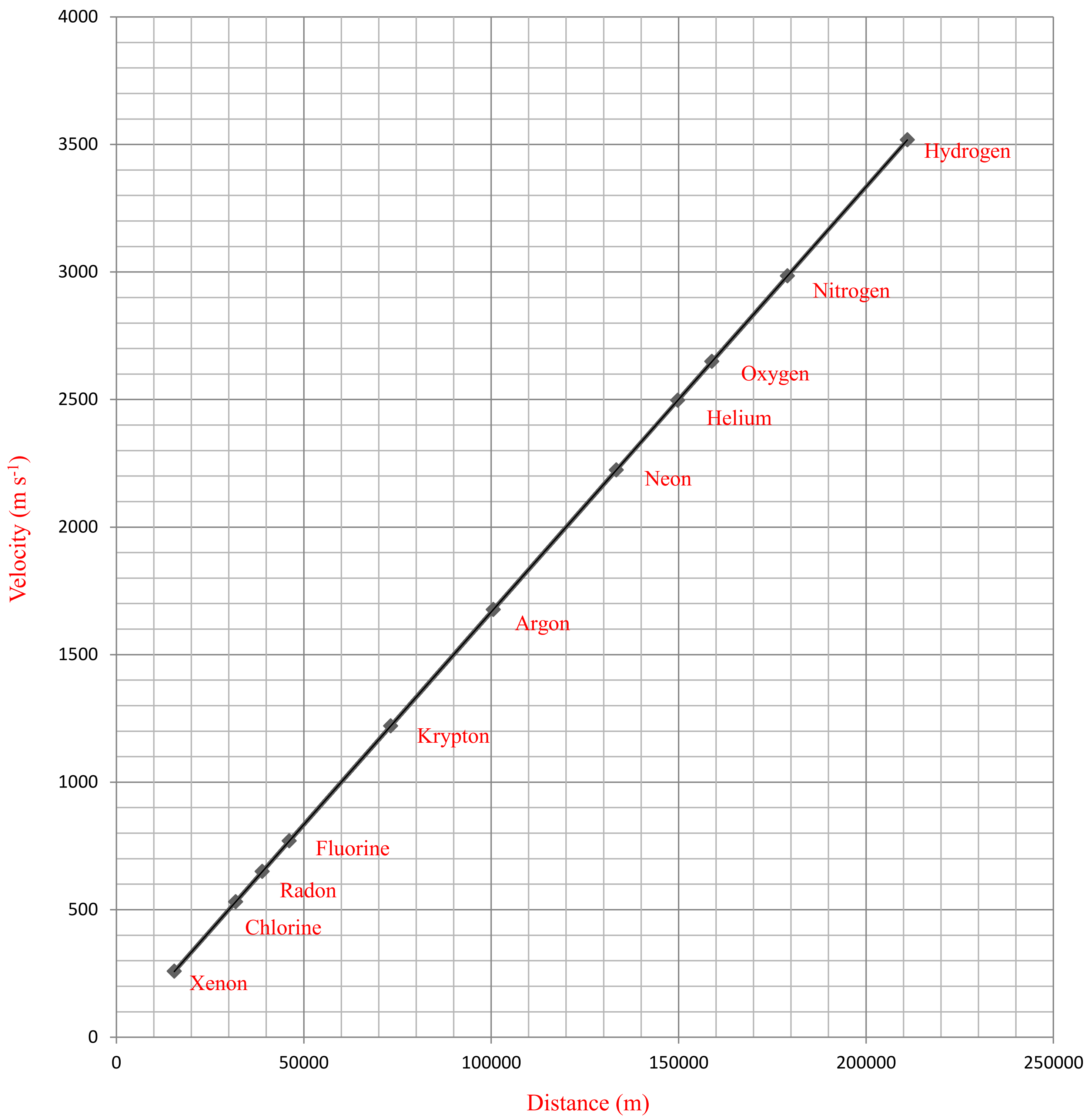
Graph 3. Velocity-distance relation plot for gas molecules diffusing at random temperature. Observation time = 1 second **(Table 4)**

(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
92.25	92.25

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
92.25	92.25

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
92.25	5535.0

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
5535.0	92.25

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
93.16	93.16

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
93.16	93.16

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
93.16	5589.6

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
5589.6	93.16

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
649.11	38946.6

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
38946.6	649.11

CONCLUSIONS

(1) The molecular diffusion model has been introduced in this paper as an alternative to dark energy.

(2) According to the molecular diffusion model, space is considered to be stationary and the distance between the large-scale structures is increasing due to their actual recession by the virtue of the energy possessed by them.

(3) Large-scale structures recede with velocity corresponding to the total amount of energy that they possess; finite amount of energy suggests constant recessional velocity that the receding structures will attain in distant future.

(4) Large-scale structures would continue to accelerate as long as they do not attain a constant recessional velocity corresponding to the finite amount of energy that they possess.

(5) The energy possessed by receding large-scale structures is greater than the gravitational influence between them. Therefore, they recede away from each other instead of remaining gravitationally bound.

(6) "Gas molecules diffusing or expanding freely inside a vacuum chamber by the virtue of vacuum energy or dark energy" has never been heard of. Such claim, if true, would only suggest that gas molecules do not possess any energy.

(7) 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.

(8) 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.

(9) 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.

(10) Since the obtained values for matter and dark energy coincide, therefore, it becomes very evident that large-scale structures possess energy instead of energy being possessed by empty space.

(11) The Universe will begin to collapse once the receding large-scale structures become energy deficient. Energy deficient large-scale structures will slow down and eventually stop with their recession and gravity will finally take over.

(12) 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, because, 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.

(13) 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).

(14) 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.

(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) No matter how drastically or 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.

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

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

(19) The similarities encountered between the velocity-distance relation plot for the receding large-scale structures and the receding gas molecules prove the credibility of the molecular diffusion model.

REFERENCES

Bars I., Terning J., 2009, Extra Dimensions in Space and Time. Springer. pp. 27-. ISBN 978-0-387-77637-8

Carroll S. M., 2001, LRR, 4, 1

Davies P., 2006, The Goldilocks Enigma. First Mariner Books. p. 43-. ISBN 978-0-618-59226-5

Durrer R., 2011, RSPTA, 369, 5102

Einstein A., 1917, Sitz. Preuss. Akad. Wiss. Phys.-Math, 142, 87

Fixsen D. J., 2009, ApJ, 707, 916

Frieman J. A., Turner M. S., Huterer D., 2008, ARA&A, 46, 385

Hubble E. P., 1929, Proc. Natl. Acad. Sci., 15, 168

"Norma Cluster". NASA/IPAC Extragalactic Database (NED)., 2006

Perlmutter S., Aldering G., Goldhaber G., Knop R. A., Nugent P., et al., 1999, ApJ, 517, 565

Planck 2013 results. I. Overview of products and scientific results. Planck Collaboration., 2014, A&A, 571A, 1P

Planck 2015 results. XIII. Cosmological parameters. Planck Collaboration., 2016, A&A, 594A, 13P

Riess A. G., Filippenko A. V., Challis P., Clocchiatti A., Diercks A., et al., 1998, AJ, 116, 1009