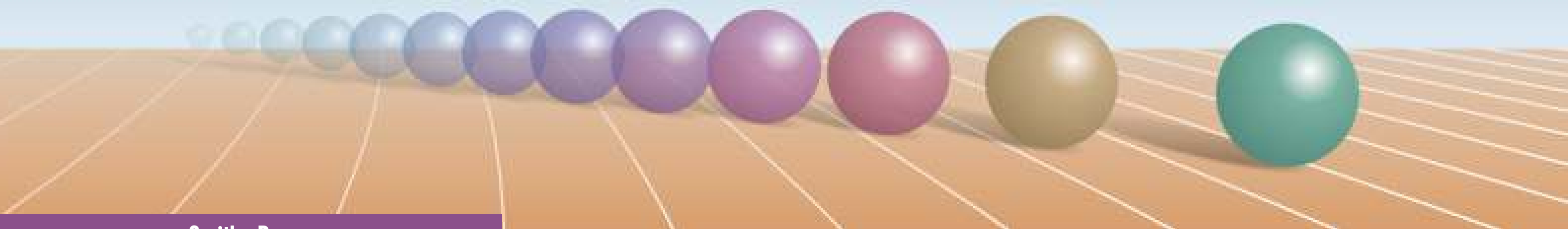
Why Do Things Move?

Interdisciplinary Paths to Exploring Motion



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Most human understanding of motion is relatively recent – whether it's the movement of the Earth, the expansion of the Universe, the perpetual motion of atoms or the mechanisms of movement in life forms. Integrating our understanding from various disciplines is crucial for a holistic approach to this phenomenon. This article suggests studying the causality of movement through various disciplines as a unifying theme between them.

"The world is always in movement." – V. S. Naipaul[1]

Do you remember the first time you saw a shooting star burn its way across the night sky? I still recall the awe I felt as a child in discovering its sudden bright movement, and then its abrupt disappearance. It was so briefly visible that it could have been a trick of the mind!

There are many such movements we see in nature that are magical. Whether it is the slippery motion of a snake, the soothing crash of waves on a beach, or the briskly infolding leaves of a touch-me-not, movements are fascinating.

Even things that seem to be still are moving. Plants move significantly even though they are rooted. Only their movement is so slow that it takes us weeks, months or years to detect it. The surface of our planet, mountains and glaciers, all move by inches over centuries. Even when there is no wind, the air around us is moving. We see this movement only when a beam of light falls into a dark room, lighting up dancing particles of dust. And light itself moves, although too quickly for our eyes to sense.

Since motion is such a widespread phenomenon, it is studied across subjects in our schools. Exploring this topic with middle-school children can be a rich and interesting experience. The urge to move is irrepressible in children – just ask any teacher who has tried to keep her class motionless! This craving to move can be usefully combined with students' zeal for asking questions in teaching this topic.

Some biology textbooks mention that movement is a characteristic of life. But geography, physics and chemistry tell us that oceans, galaxies, and all molecules move too! So, how is movement a trait of life alone? Actually, is **anything** in the Universe stationary? And what makes all these things move? Such questions can be common themes we use to approach the topic of movement from an interdisciplinary perspective [2].

What is movement?

"I do not define Time, Space, Place, and Motion, as being well known to all. Only I must observe that the vulgar conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices…" -- Sir Isaac Newton [3].

An early challenge in preparing an interdisciplinary curriculum is to become familiar with the language used in different disciplines for similar concepts[4]. For instance, what is the difference between "movement" and "motion"? How about "locomotion" and "displacement"?

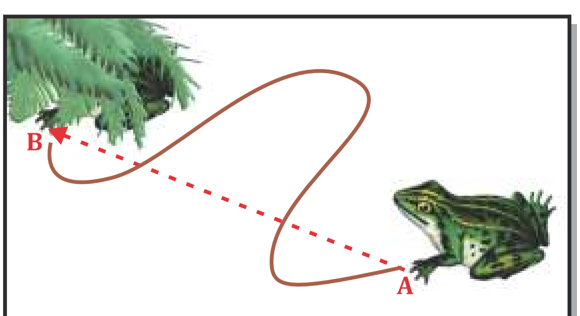
Then, there are many terms specific to each discipline that are useful to know. Some such terms in this topic would be: speed, velocity, acceleration, momentum (in physics); rotation, revolution (in geography); bone, cartilage, muscle and joint (in biology). We should also check whether the same words have varied meanings in different subjects.

So, is there a difference between "movement" and "motion"? Not really, although one of these words is used more frequently in each discipline. For example, our physics textbooks usually use the term "motion" rather than "movement". Both movement and motion refer to change in position in space over time.

> We say that the Himalayan tectonic plate **moves** because it **changes position by around two centimeters each year,** moving towards Central Asia[5].

Does "movement" mean the same thing as "locomotion" or "displacement"? No, because the last two terms have a more specific meaning than just "change in position".

In biology, "locomotion" refers to the complete relocation of an organism's body to a new position. So, all movement by an organism is not locomotion. For example, you have not undergone locomotion if you move your hand while sitting - there is a movement of the hand but no relocation of your body.



Look at this picture of a frog that moved from an exposed position at Location A to the camouflaged Location B. It moved along the path shown by the dark brown curve.

Its displacement, however, is much less, and is depicted by the dotted arrow from A to B. The frog had undergone locomotion as it moved from A to B. When it crouches or blinks its eyelids at point B, however, it moves but doesn't show any locomotion or displacement.

Displacement, on the other hand, is a term from physics. It refers to the least distance between the initial and final positions of an object. It also indicates the direction of movement. In the previous example, if the hand had moved 10cm to the right side of the body, its displacement would be 10cm towards the right.

The different kinds of movements around us

An excellent way to introduce the topic of 'movement' in the middle-school classroom is to start with exploring individual student observations. Ask students to observe and list out movements around them. Remind them to look for all kinds of movements – of animals, of things moving in the wind, the automated movement of machines, even the flow of water.

Once they've prepared their lists, ask student to mimic the movements they've observed, and demonstrate them in class. *Kinesthetic learning,* a way of learning by doing, can be used frequently in teaching this topic. As Susan Griss says, "Simply by getting students out of their seats, we begin to break the mould of "I-don't-really-want-to-be-here education". It's a crime to make students sit still while learning about movement[6].

It will be useful to end this activity by encouraging students to sort the different kinds of movements they have observed, by type. So, what are the different kinds of movements around us? The classification of movements, again, varies by discipline.

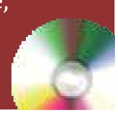
Ask a physicist, and he will drop names such as 'translational', 'periodic', 'harmonic' and 'rotational'. A biologist, on the other hand, will use nasty words such as 'nastic' and 'tropic', and, then, bombard you with 'crawl, climb, hop, glide, hover, undulate…' An earth scientist might mention 'rotations, revolutions, waves, tides and currents'. A chemist would talk of 'vibrations, Brownian motion', and so on. How do you make sense of this cacophony?

Take a deep breath, and remember that all these categories are here for our convenience. We only need to go into as much detail as is needed for our students.

Let's start with the basic kinds of movement as defined by **Mechanics.** Mechanics, as you know, is the field of physics that deals with the motion of bodies under the action of forces. In mechanics, movement can be of four kinds.

Movement that results in a change of location is called ***translational motion***. Is there any other kind of movement, you ask? Well yes, there can be. If, for instance, a train travels from Bangalore to Delhi and then back to Bangalore, it has moved quite a bit. But there is no net change in its position. Similarly, an object that repeatedly moves between 2 positions exhibits ***oscillatory motion.*** If, on the other hand, an object spins around itself without going anywhere, it shows ***rotational motion****.* And finally, an object whose movement is unpredictable undergoes ***random motion****.*

A caterpillar that crawls down a plant to reach the ground shows translational motion. The repetitive movement of a pendulum is an oscillatory motion. The spinning movement of a CD in a CD player is rotational motion. The movement of molecules in a gas is unpredictable, and is random motion.



Animal movements

"Flying insects and birds beat their wings up and down, swimming fishes beat their tails from side to side, and running mammals swing their legs backward and forward. In all these cases, a structure that has mass is oscillated in a fluid (either air or water), which resists its motion." – R. McNeill Alexander [7].

So far, we've looked at four kinds of movement. Isn't that enough for our classes? Well, look at the difference between saying "kangaroos hop while horses gallop" and "kangaroos and horses undergo translational motion"! Almost all animal locomotion is translational motion; when we wish to describe the movement more precisely, we use other words.

Kinds of animal locomotion depend on the medium in which movement occurs. All movement under water is ***swimming,*** although this can be further divided into categories such as ***undulation*** and ***propulsion.*** Movement in air is ***flying*** of various kinds – ***gliding, hovering*** and ***flapping.*** Movement below the ground is usually ***burrowing.*** Movement on land is the most diverse, and can be a ***walk, run, hop, climb, jump*** or ***crawl.***

All these movements result in translational motion. But are other kinds of motion observed in animals? Think of the beating of your heart – it keeps beating, but in the same place inside the chest. This is an example of oscillatory motion, where the heart moves back and forth between two positions. Now move your head from side to side. The pivot joint in your neck which allows you to move your head in this manner relies on rotational motion. Can you think of other examples of oscillation and rotation in animals?

Plant movement

"They have to fight one another, they have to compete for mates, they have to invade new territories. But the reason that we're seldom aware of these dramas is that plants of course live on a different time-scale." -- Sir David Attenborough[8].

We don't usually think of plants as moving, but they have lots of action in their lives. The ones that catch our eyes are the ***rapid plant movements****.* These movements occur within a fraction of a second or in a few seconds. Examples of such rapid movements include the Venus flytrap snapping shut on its prey, and leaf movements in the touch-me-not and the telegraph plant. The quickest known movement in plants is the catapulting of pollen from white mulberry trees – this happens at half the speed of sound[9]!

However, most plant movements are mind-numbingly slow, occurring over weeks and months. These movements take place in response to stimuli such as light, water, gravity, chemicals and the sun. The most famous of these movements is the "solar-tracking" done by sunflowers. Some other examples include the growth of primary roots towards gravity, and the bending of stem tips towards light.

These plant movements look much more interesting when captured through time-lapse photography and speeded up. Take a look at some fascinating time-lapse videos of plant motion at this website created by Roger P. Hangarter: http://plantsinmotion.bio.indiana.edu [10].

Movements of heavenly bodies

"...Our sense of sight presents to us four satellites circling about Jupiter, like the Moon about the Earth, while the whole system travels over a mighty orbit about the Sun in the space of twelve years..." -- Galileo Galilei and Johannes Kepler [11].

We've looked at movements in living creatures which are similar to us in scale of size. Let's now look at movements at a larger scale - of planets and stars and the Universe itself.

For most of history, humans have thought that the Universe revolved around the Earth. After all, didn't the Sun rise in the east and set in the west? And didn't stars and planets move around the Earth at night? Our current, drastically altered understanding of movements in the Universe was achieved through the work of many courageous scientists who challenged authority.

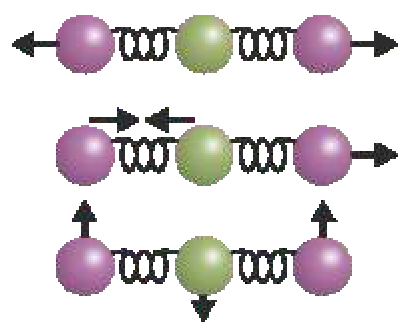
The Geocentric theory of the Universe claims that the Sun, Moon, stars and planets all circle the Earth. Nicolaus Copernicus did not publish his work that questioned this theory until just before his death, since it was considered blasphemy! Galileo Galilei was persecuted by the Church for daring to say that it was the Earth that moved around the Sun rather than vice versa. Modern science began once humans accepted that the Earth is not the centre of the Universe. Rather, the Earth rotates around itself from West to East every 24 hours – and so celestial bodies seem to move around us from East to West.

After the Greeks, Copernicus was the first to suggest that the five visible planets and Earth move around the Sun. Galileo made detailed observations using his telescope and discovered the presence of satellites around Jupiter. And Johannes Kepler proposed that the orbits of planets and satellites are not circular but elliptical. With the discovery of further planets in the solar system (Uranus, Neptune and Pluto), the movements of planets in the sky were mostly explained by Kepler's ***Laws of Planetary Motion***.

> We now know that the Earth rotates around itself and revolves around the Sun. What kinds of movements are these?

By the early twentieth century, it was accepted that even the Sun is not at the centre of our galaxy. Instead, it is one of many stars on a minor arm of the Milky Way. And Edwin Hubble was able to prove that there are many thousands of such galaxies in the immense Universe. Even more interestingly, Hubble's data showed that the further a galaxy was from the Earth, the faster it was moving away. This implied that most galaxies were moving away from each other at ever-increasing speeds. And, therefore, that the Universe was expanding!

Movement of molecules



Molecules vibrate in many different patterns
Ref: http://scied.ucar.edu/molecular-vibration-modes

"For thou wilt mark here many a speck, impelled

By viewless blows, to change its little course,

And beaten backwards to return again,

Hither and thither in all directions round.

Lo, all their shifting movement is of old,

From the primeval atoms..."

– Titus Lucretius Carus [12].

From planets and galaxies, let's now move to the other end of the scale, and peer at the sub-microscopic level. We now accept readily that all matter is made up of atoms or molecules. But for centuries, atoms were just a fantastic concept, with no real evidence. However, Lucretius' quote above, made more than 2000 years ago, held the germ of proof for them!

Robert Brown, while studying pollen under his microscope, observed some particles ejected from pollen. These particles were continuously moving in water in a jittery manner as if they were alive. This random motion of particles suspended in a liquid or gas (fluid) is now known

In his philosophical poem, Lucretius described the eye-catching motion of dust particles seen in a beam of sunlight. He surmised that dust was kicked around by invisible moving atoms in the air. We now know that this motion of dust particles is actually due to thermal currents. But this motion is remarkably similar to Brownian motion which helped confirm the existence of atoms and molecules.

as Brownian motion. Decades later, Albert Einstein explained that these particles jittered due to collisions with continually moving atoms or molecules of the fluid itself. The motion of the invisible atoms was revealed by their moving the larger, visible particles!

We've just seen that molecules of a fluid are in continuous motion. What happens to the molecules of a solid? It turns out that solid molecules move too. The manner of movement of particles depends on the state of matter, however. This means, for instance, that water molecules move differently in ice, in liquid water, and in water vapour.

Particles of solids are tightly packed together in a regular arrangement. Yet, solid molecules vibrate and rotate about their fixed position. Vibration is a kind of oscillation about an equilibrium point. Despite these movements, solids are rigid due to the tight bonding between their molecules.

In liquids, particles are held together more loosely. Liquid particles are close but are also able to slide around one another freely. This is why liquids are able to take the shape of their container. Liquid particles exhibit vibration, rotation and translation.

Gas particles, too, show all these movements. But there is much more distance between gas particles than in liquids. Also, gas molecules move rapidly in all directions. This is why gases are able to fill any container that they are kept in.

Causes of movement

"What is the prime mover, the weaver who guides the flashing shuttles?" -- Edward O. Wilson[13].

There is a wide variety of movement in the world around us. Some of these are invisible to our eyes and some happen in our immediate environment. Others are at a scale so much larger than us that they are difficult to comprehend. But why and how do all these things move at all?

The answer to this question is quite complex and depends on the context where we raise it. Animals and plants move for reasons familiar to us. But why do molecules of a gas, or planets and galaxies move? Is there any common cause behind all these motions? It is a good idea to begin raising these questions in middle school for students to ponder over. And the best place to begin is with the familiar -- living creatures.

Why do animals move?

If you ask your students this question, they are likely to give you answers such as "to escape danger" and "to look for food or water". One way to further the discussion is to ask students why

While we readily comprehend movement in animals, it takes more imagination for us to grasp the concept of movement in plants. Sources for illustration (Animal): Garvie, Steve. The Great Trek. 2010. Wikimedia Commons. Web. 15 Apr. 2015. https://commons.wikimedia.org/wiki/File:The_Great_Trek.jpg. Attribution-Share Alike 2.0 Generic License: https://creativecommons.org/licenses/by-sa/2.0/deed.en. Sources for illustration (plants sprouting): Favreau, Jean-Marie. Sprouter. 2006. Wikimedia Commons. Web. 15 Apr. 2015. https://commons.wikimedia.org/wiki/File:Sprouter.png. GNU Free Documentation License, Version 1.2 or later: https://en.wikipedia.org/wiki/GNU_Free_Documentation_License) animals migrate with changing weather. You could also describe animal movement in search of mates using the examples of nuptial flight of ants and termites.

> We can see from these that the ultimate cause of movement in animals is the need for food, shelter, mates and so on.

Next, it's useful to look at how movement is effected in animals. The immediate cause of movement in most animals is the contraction of muscles.

In vertebrates, muscles and bones act together as levers to bring about movement[14]. A lever is a simple machine used to produce a large force by exerting a smaller force. The principle of levers is used to produce efficient movements in vertebrates. Ask students how their muscles and bones might act as levers.

Another interesting fact is that most body movements are brought about by muscles working in pairs. Make students reflect on why muscles work in pairs. A clue to the answer is that any muscle can contract to bring about movement in only one direction.

Biceps and triceps are such a muscle pair – when the biceps contract, triceps relax, and vice versa. The contraction of biceps causes the elbow to bend; the contraction of triceps straightens the elbow again. So, muscles work in pairs to move body parts in both directions.

Why do plants move?

It's interesting to observe whether students realize that plants move for many of the same reasons as animals. The only difference, of course, is that there is no actual locomotion in plants. Ask students to name specific plant movements, and then, to consider why these occur.

For example, stems move towards light, and roots towards water, to help the plant prepare food through photosynthesis. The movement of the Venus flytrap is to help the plant get scarce nutrients, such as nitrogen, by trapping insects. The leaves of the touch-me-not close when touched, as a defence against predators. Flowers open and close to maximise their chances of pollination, fertilization and seed-formation.

> The ultimate cause of movement in plants is, again, the need for food, defence, reproduction and other necessities.

But how exactly do plants bring about movement? After all, they have no muscles, no bones and most importantly, no nervous system. The answer to this question involves an interesting mix of biology and chemistry. If your students are familiar with the basics of plant cell structure and some chemistry, you could study one or two examples of plant movement in some detail.

Slow movements in plants are brought about by different rates of growth of different plant parts. For example, when seedlings are placed inside a room, their stems bend towards the window, in the direction of light. This movement is due to elongation of the part of the stem away from light. This asymmetrical growth curves the stem towards light. Chemicals, known as growth hormones, bring about this elongation. Growth hormones make cell walls more elastic, and therefore, cells grow longer by accumulating water [15]. And this growth hormone is directed towards cells in the dark part of the stem by the action of other chemicals that detect light.

Rapid plant movements happen through a combination of phenomena. One such phenomenon is "acid growth" that is found in the Venus flytrap[16]. When the hairs of its leaf are touched, there is a change in electrical potential of the leaf. This change releases a flood of H^+ ions into the cell walls of the midrib. The H^+ions make the region more acidic, and dissolve parts of the cell wall. Cells, as a result, become free to expand by the accumulation of water. The outside of the leaf expands rapidly and so the trap snaps shut.

There are many such proximal causes of movement in plants. And we are still exploring these mechanisms to understand them better.

In the case of both animals and plants, we've seen that movement is caused by the need to maintain life – by locating necessities for life and through reproduction. And yet, we're not quite sure what this "life" is that seeks to perpetuate itself.

Why do planets, stars and galaxies move?

We've seen a variety of movements exhibited by celestial objects - they spin (or rotate) around themselves, revolve around other bodies and speed away from the rest of the Universe. But why these objects move is a question that has baffled and intrigued humans for centuries. Students need to be introduced to the truly mysterious nature of the Universe. They could be encouraged to guess at reasons for these movements. They could also read up and find answers to this question on their own, before discussing these in the classroom. Here, we'll look at a brief overview of probable causes for the three kinds of movement mentioned earlier on.

The rotation of the Earth around itself creates the impression that the Sun and the stars revolve around it. This photograph captures the apparent motion of stars over 91 minutes in the night sky. Source: Lee, James Ronald. 91 Minutes of the Night Sky. 2010.Wikimedia Commons. Web. 15 Apr. 2015. https://commons.wikimedia.org/wiki/File:91_minutes_of_the_night_sky.jpg.

It's been observed that everything in the Universe spins – planets of the solar system, the sun, other stars, entire galaxies - **everything** spins [17]. And within a system – such as the Milky Way galaxy or the solar system – most objects spin in the same direction. In the solar system, all planets, except Venus and Uranus, rotate in the same direction as the Earth. This is because the spin itself seems to have developed as a result of the formation of these systems.

For instance, the solar system was formed within the Milky Way 4.5 billion years ago as a result of some force, possibly shockwaves from a nearby supernova[18]. This force caused a cloud of hydrogen gas to collapse on itself, through gravity. The different initial momentums with which Hydrogen particles moved towards each other, added up to produce a spin to the entire system. Similar phenomena that led to the formation of galaxies also causes them to rotate.

Now, why do Earth and other planets orbit the Sun? Planets are pulled towards the sun by gravitational force in the same manner as an apple falls to earth. The reason the Earth doesn't fall into the Sun is because it also has a sideways velocity at right angles to the Sun[19]. This sideways motion is a remnant from when the Earth was initially formed in the solar system. The sideways velocity is driving the Earth away from the Sun, while gravitational force is pulling it towards the Sun. These two are in perfect balance, and so the Earth neither falls in nor moves away. Instead it orbits the Sun continually.

Finally, why are galaxies in the Universe speeding away from one another? The answer to this question is the Big Bang[20]. When the movement of galaxies is traced backwards in time, they all seem to originate from a single point.

> The Big Bang theory was suggested to explain the origin of the Universe from this "singularity" – an extremely small, extremely hot, infinitely dense point. We don't know where the singularity came from, or how.

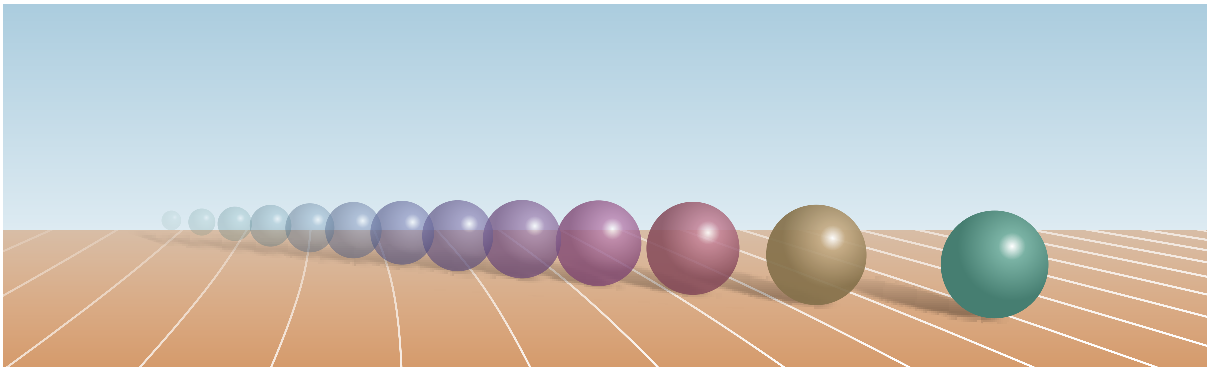
The Big Bang theory claims that 13.7 billion years ago, this singularity inflated, expanded and cooled to form the current, expanding Universe[21].

In summary, we can see that one major cause of movement of celestial bodies is gravitational force. But other causes of movement are really unknown to us – and so we guess at things such as supernovae or the Big Bang. The important thing is to impart a sense of wonder about the Universe to our students.

Why do atoms and molecules move?

Earlier, we saw how the motion of atoms and molecules varies by states of matter. But why do these particles move at all? Are there any molecules that are completely immobile?

One way to elicit guesses from students in answer to these questions is to ask them how



change in states of matter is brought about for water. Of course, we know that ice on heating changes to water and on further heating, water changes to vapour. And this phenomenon can be reversed by cooling.

The next task is to draw out students to see connections. Ask them what relation there might be between how matter changes state and how particles move in different states. They should be able to see that particles move faster on heating and slow down on cooling. The term **kinetic energy** could be introduced here as the energy of motion. The faster an object moves, the more kinetic energy it has.

Then, question students about how the **temperature** of a substance changes when heated. Let them try and define what temperature means. Of course, temperature measures the intensity of heat of an object. But the connection here is that temperature is a measure of the average kinetic energy of particles in an object. The faster the particles in the object move, the higher its temperature[22].

We've seen that particles in matter move faster when heated. So is it possible to make particles stop their movement by cooling them enough? The Kelvin temperature scale is based on this idea, since scientists theorized that the volume of a gas becomes zero at -273.15°C. This temperature of -273.15°C is considered the **absolute zero** or 0 Kelvin[23]. By definition, all molecular movement is supposed to stop completely at the absolute zero.

But there are several issues with this. There is no place in the known Universe which is at absolute zero. And it is theoretically impossible for us to create an absolute zero, although we have been able to get pretty close [24]. Finally, quantum mechanics argues that it is impossible to measure whether particles are in motion at absolute zero. And even if we were somehow able to measure motion at this temperature, particles would still have a small amount of vibration and rotation[25]! So, each and every particle in the Universe is in motion. And we don't really know why.

Conclusions

Let's repeat the question we began with – can we say that movement is a characteristic of life? After all, everything in the Universe moves. It seems more appropriate to talk of living creatures as exhibiting purposeful movement in **response to stimuli.** This is the kind of nuanced understanding that interdisciplinary studies ideally promote.

We have studied the topic of movement from multiple perspectives here for a specific reason – to try and integrate different points of view. While we learn about the world through an artificial division of disciplines, interdisciplinary curricula attempt to see the whole. Hopefully, we now have an understanding of motion that encompasses concepts from different disciplines.

Of course, the more we probe why things move, the more questions arise in our minds. In spite of all the details we study, the ultimate cause of movement in the Universe eludes us. This awareness that there is much that is unknown is an insight we must pass on to our students. For only then is an urge created to go beyond boundaries of the familiar and the known.

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