Concepts (II)

3-00 Remaining Concepts

The remaining concepts are presented in this chapter. In what follows, the word *object* or *system* refers to both: objects and systems-of-objects. For emphasis, where necessary, we shall mention both.

(F) Natural States of Objects in the Universe
(G) Unnatural states of objects
(H) Achieving the purpose of physics
(I) Centers of mass of objects
(J) When do we use Physics?

3-F-i Natural State of Objects Around Us & Beyond

If you think that the natural state of objects in our universe is *state of rest*, you are sadly mistaken! (And so was the great thinker and philosopher Aristotle.) Strange as it may seem, but it is a fact that the natural state of almost all of the objects in the universe is *state of motion*, uniform motion. Some examples are given in Table 1.

Table 1: State of Motion

Speed of	Approximate Value of Speed		
	MKS units	familiar units	
earth, as it orbits the sun	30,000 m/s	67,100 mph	
earth, as it spins around itself	464 m/s	1,040 mph	at the equator
moon as it orbits the earth	1023 m/s	2300 mph	
light waves	300,000,000 m/s	671,000,000 mph	in vacuum or air
sound waves	340 m/s	760 mph	in air
an electron in an hydrogen atom	2,200,000 m/s	4,890,000 mph	
oxygen molecules in air in still air (such as inside a room)	480 m/s	1,070 mph	at $20°$ C
nitrogen molecules in air in still air (such as inside a room)	510 m/s	1,140 mph	
water molecules in still water	600 m/s	1,340 mph	
free electron in copper	1,600,000 m/s	3,580,000 mph	

3-F-ii State of Motion

All objects in our universe are in a state of motion. Living beings on our earth are capable of being in states of motion, The motion is usually at a constant pace and takes place in straight lines or in segments thereof. We human beings, tend to walk or jog or run, at a constant pace in straight paths (or segments thereof). All vehicles of transport also have similar modes of motion. Same can be said of other living beings (bugs and birds, for example). So we make an intuitive guess: all objects that move on flat surfaces (or their equivalents) tend to move in straight line paths, at a constant pace.

All celestial bodies are in motion too. There isn't a single heavenly body that is fixed in the skies and doesn't move. Many heavenly bodies (including our earth) have two types of motion: they spin around themselves and then they revolve around some other star. Not only that the objects on a macroscopic scale are in motion, objects on the microscopic scale, such as molecules, atoms and the sub-atomic particles, are also individually *and* independently *and* perpetually in motion.

So, as everything is in motion, nothing, in our universe, is really at rest. State of rest, under the circumstances, cannot be the natural state of objects in the universe.

This situation should really be no surprise to us. As we know, a basic property of material objects is that they pull one another. So they keep pulling each other and cause them to be in motion.

We are also rudely awakened to the fact that there is no absolute state of rest:

There is no such thing as an "absolute state of rest"

First there was no "absolute reference frame" and now there is no "absolute state of rest"!

What's the world coming to?

3-F-iii What About Mountains?

In spite of all the perpetual motion of all the bodies in all the universe, we cannot deny that our eyes do see objects that have been sitting in one place for ever and ever and ever and have no intention of moving (mountains, for example). Are they not at rest?

We wish to point out that objects that are at rest for one observer are not at rest for *all* observers. In fact, given an object at rest, it is *always* possible to find an observer for whom the object is not at rest. A state of rest, therefore, is not a true state of rest and should really be called an *apparent* state of rest.

3-F-iv The "Apparent State of Rest": (a) No Relative Motion.

Objects appear to us to be at rest because they have no motion relative to us. Often two objects move *together* and have no motion relative to one another. These objects are at rest with respect to one another only but not at rest for the entire community of observers. Consider our belongings inside our car. These belongings are at rest for us but not to the observer sitting on the pavement (the bystander). The earth is like a giant motor car where the mountains and all are our *belongings* that are at rest for us. To an observer outside the earth (one on the moon, may be), we shall all be moving at a fast speed. We conclude that objects that are *moving together as one system*, are *at rest* **only** with respect to one another and ***are not really at rest***. Thus the lack of relative motion causes objects to be in ***apparent states of rest***.

3-F-v The "Apparent State of Rest": (b) "No-Net-Force".

Another reason for an object to be in an *apparent state of rest* is that the object is being denied its basic human right (natural tendency) of keeping moving and thereby is being *forced* to be at rest. When an object is subjected to a number of mutually neutralizing forces then there is no *net force* on it. As a result, an *apparent state of rest* is ***created.*** Such a state of rest can be fragile too. Should one force per chance become weak, the state of rest will come to an abrupt end and the object will begin to move instantaneously with an ever-changing speed. Every single object that is not moving is under the influence of *at least two* mutually neutralizing forces. This is true of a book placed on the table, a needle in a hey stack, or us people sun-bathing in dolphins' land.

The above leads us to conclude that no object (in the universe) is truly in a state of rest. A given state of rest is only an *apparent* state of rest. We postulate:

All states of rest are only "apparent" states of rest

3-F-vi The "Apparent State of Rest": (c) No-Net-Force?

We have some problem here!

Because all objects in the universe pull one another we find that there is no *force free* region of space either on the earth or elsewhere in the universe! At least one force (the force of pull) is present in every nook and corner of our universe. Consider the earth. It has an enormous mass and it pulls everything toward its center. This force of pull cannot be disabled or switched off! There is absolutely no way we can get rid of it.

How on earth then, can objects on earth be at rest?

A little deliberation shows that objects on the earth are at rest only when they are being supported by other object(s). A book-at-rest on the table is being supported by the table. The mountain is supported by the ground underneath it. A chandelier is being supported by the chain with which it is hung from the ceiling. In fact *every* single object that is at rest, is being supported by another object.

Simple observations lead us to the following important conclusions:

(i) the supporting object exerts a force of support on the object that it is supporting, thereby causing it to be in an apparent state of rest.

(ii) this force of support is directed vertically upward so that it can neutralize the earth's force of pull (which invariably always acts in the vertically downward direction).

(iii) the force of support must be equal *exactly* to the force of pull of the earth *(matching it up to a very large number of decimal places)!*

Above arguments apply to objects at rest against the earth's force of pull. Parallel arguments exist for objects at rest in other situations.

3-F-vii State of Motion: Motion in a Straight Line

Consider an object that is set in motion on a flat surface, by applying some impulsive force. The object moves off in a straight line, with uniform speed. After moving through some distance, the objects stops. It clearly shows that the object did not have a uniform motion. As it did start off with a uniform speed, we will have to admit that a retarding force must have acted upon the object along its path and that's what caused the object to stop. This retarding force is *force of friction*. To understand the role of friction, consider a marble on a flat hard floor. Give it a little push (impulsive force) and it will start off in a *straight line.* It will slow down and eventually come to a stop. Do the same thing with a hockey puck on the same hard floor. Given an equivalent push. the puck will be found to move off in a straight line but will travel a much shorter distance. Marble was stopped by the force of *rolling* friction while the hockey puck was stopped by the force of *sliding* friction. The reason for the disparity in the length of travel (in the two cases) is the difference in the strengths of the respective forces of friction. The stronger the force of friction, the smaller will be the distance of travel. As the strength of the rolling friction is far smaller than that of the sliding friction, the marble was able to traverse a much longer path, compared to the puck. Stretching our imagination, we now imagine a friction-free surface and it will be correct to expect that the distance of travel will be unlimited.

3-F-viii The "State of Uniform Motion in a Straight Line" and "No-Net-Force"

As there is no *force-free* region of space, in our universe, how can an object have a never-changing (or constant or uniform) motion in a straight line? In view of the arguments applied to the state of *apparent-rest*, we have to admit that there must be at least one other force acing on the object to counter the force that acted upon the object in the first place. If the original force acted to increase the magnitude of motion, the *counter-force* must act to decrease this magnitude by an equivalent amount. In case of a car that moves at constant (say) 30 miles per hour, the force of the engine is neutralized by the force of friction that the surface of the road exerts on the wheels of the car. For the drops of rainwater falling from the clouds, it is the force of air-resistance that acts as the neutralizing force, thereby causing them to fall with uniform speed (called the "terminal" speed). Objects travelling in free space (away from the gravitational pulls of stars) will continue to travel with uniform motion.

Just as *no-net-force* is mandated for objects that have to be in *apparent states of rest* (for one reason or other), *no-net-force* is also mandated for objects that are in *states of uniform motion in a straight line.*

How very curious!

3-F-ix *The Importance of "No-Net-Force". The Concept of Equilibrium*

We are now in a position to introduce the concept of *equilibrium*. We define *equilibrium* by the following statement:

When an object is governed by "No-Net-Force", it is said to be in "equilibrium"

alternatively:

When a set of forces, acting on an object, together neutralize one another's effect on that object, the object is said to be in "equilibrium".

The minimum number of forces acting on the object at equilibrium is *two*. There is, however, no upper limit to the number of forces. The combined effect of all these forces will be found to be zero.

3-F-x Usefulness of Equilibrium

The concept of *equilibrium* in *mechanics* describes (i) the (apparent) state of rest, and (ii) the state of uniform linear motion.

Objects in equilibrium, will have the following two attributes:

(1) The object is either not moving at all or is moving by traversing equal lengths in equal intervals of time, in a straight line. The x-axis (or the y-axis or the z-axis) of the observer's reference frame may be aligned with this straight line.

(2) Forces neutralize one another, in each of the three modes, considered individually. There is as much effort to pull the object (say) to the right as there is to pull it to the left; etc. (Think of a scoreless game of tug-of-war.).

3-F-xi Uselessness of Equilibrium

In spite of all the fanfare and grandeur, *equilibrium* did not perform to our full satisfaction. The case of uniform motion in a circle (and ellipse) is sadly left out. These are two-dimensional motions. The object travels in a plane (such as a surface) and not in a straight line. So we cannot expect it to traverse equal lengths in equal intervals of time. Surfaces have areas. What would be natural, in this case, is to expect the object to traverse equal areas in equal intervals of time. This is indeed what the object does. But *ALAS*! For this type of motion, the net force is not zero and the condition of being in equilibrium (*no-net-force*), gets thrown out through a tiny crack in the wall.

We are all familiar with ducks. "If it looks like a duck, walks like a duck and quacks like a duck, then it ***is*** a duck". Not so for rotating objects. Because the very act of rotation requires an unbalanced force to be glued to the object for the entire duration of its rotation Consider an object going round and round in a circle on a table with uniform speed (a toy train, for example, or a merry-go-round). The object is at rest in the radial mode as the radius of the circular path does not change. This spells equilibrium. It is at rest in the axial mode because it doesn't get lifted off the table and doesn't sink in the table either. Spells equilibrium again. The angular velocity of the object (both magnitude and direction) is uniform or constant. This spells equilibrium too. So, the object is in equilibrium in all 3 of its modes independently and simultaneously. However, as the net force is not zero, the object is not in equilibrium!

What would you call something that looks like a duck, walks like a duck and quacks like a duck but is *not* a duck? Let's call ours *lame-duck equilibrium.*

3-F-xii Natural State of Objects (2) State of Equilibrium (including the Lame Duck Equilibrium)

We now confidently rephrase our statement in regard to the *natural state* of objects

The natural state of almost all objects and systems-of-objects in our Universe is:
"State of equilibrium (including the lame-duck equilibrium)"

Objects at rest, are obviously in equilibrium. Objects with uniform linear motion are also genuinely in equilibrium.Objects with uniform areal motion or are in partial-equilibrium. Examples of equilibrium (many quite astonishing) proliferate in all other branches of physics as well. Just to quote a few, objects at room temperature are in *thermal* equilibrium. A charged capacitor is in *electrostatic* equilibrium. Electric motors and electricity generators are in *electromagnetic* equilibrium. The needles of all meters (speedometers, for example) are in *electro-mechanical* equilibrium. Thus we are justified in stating that:

Almost all of the systems in our universe are, almost all of the time, in states of equilibrium (including the lame-duck equilibrium).

Probably the only things around us that are not in equilibrium, almost all of the time, are (i) roller coasters and (ii) the Dow Jones's Index; (a familiar news item: *The Dow Jones Index had a roller coaster ride today*).

3-F-xiii Genuine Equilibrium States

In what follows, we shall talk of objects and systems of objects that are in states of genuine equilibrium only. The arguments can be applied to objects and systems that are in states of lame-duck equilibrium also. This amounts to saying that, for now, we shall talk of objects and systems that are either at rest or moving in a straight line with uniform motion.

3-G-i Unnatural States of Objects

Because the *natural states* of almost all of the objects for almost all of the time, has been determined to be the *equilibrium states*, we now (naturally) define the *unnatural states* of objects as their *non-equilibrium states*.

3-G-ii Non-Equilibrium States of Objects

The *non-equilibrium states* of objects are those states in which they are neither at rest nor are they moving with uniform linear speeds. Such systems necessarily move with *ever-changing* speeds. A system moving with an ever-changing speed is said to be *accelerating*. Thus all objects and systems in non-equilibrium states are always accelerating

Even though almost all of the systems for almost all of the time *are* in states-of-equilibrium (real or pseudo), they may not be glued to those states. The earth and the moon are, of course, for ever glued to their speeds of rotation and revolution, a motor car is not. It can travel at different (uniform) speeds under different circumstances. In between changing speeds, the car does try to remain in equilibrium by maintaining uniform speeds otherwise the passengers will be very uncomfortable.

The same is true of a whole lot of other things also. They are not glued to one specific equilibrium states. Changes in states of equilibrium may occur as often as necessary, or as dictated by an object's own initiatives or as a result of its interactions with its neighbors.

3-G-iii Non-Equilibrium States as "Activity Regions"

A non-equilibrium state occurring in between two equilibrium states, is called an *activity region* of the object. In an activity region, the object necessarily *accelerates* as the system progresses from one equilibrium state to another equilibrium state.

As an example, consider a car travelling at a uniform 30 *mph* speed. As it enters the throughway, it accelerates to 65 *mph* and cruises with that speed. Travelling at a uniform speed of 30 *mph* is an equilibrium state and so is cruising at 65 *mph*. In between these two equilibrium states lies the non-equilibrium state in which the car *accelerated* from 30 *mph* to 65 *mph*. As another example, consider an electron. The ground states and the excited states of electrons are all equilibrium states. As an electron moves from one state to another, it goes through the activity region. Similarly, objects that begin moving *from* a state-of-rest, or come *to* a state-of-rest from a state-of-uniform-motion pass through activity regions.

3-G-iv "Lifetimes" of Activity Regions

As objects and systems-of-objects *tend to stay* in states of equilibrium, any departure from equilibrium is unnatural. If a system needs to change its state of equilibrium, it would tend to do so in the shortest possible time. It is observed that all systems tend to go through their respective activity regions in as short a time as possible. This enables *almost all of the objects* to spend *almost all of their time* in equilibrium states. Additionally, the smaller the time spent in the activity region, the greater is the efficiency.

Consider a sprinter taking part in Olympics. To be on top of the world, he (or she) must complete the run in the shortest possible time. The most effective way of minimizing time would be to keep accelerating from start to finish. But can the sprinter accelerate for the entire length of a race? The answer is no! Strange as it may seem, but even for the 100 meter dash, no athlete can keep accelerating for the full 100-meters! They accelerate for a fraction of total time and then cruise with a uniform speed. They may accelerate again for another small interval of time and then revert to cruising (at the higher speed, of course).

We state that:

(1) A non-equilibrium state is an "Activity Region" which is encountered when a system moves from one equilibrium state to another

(2) Activity Regions are short-lived

Consider the following diagram. It displays an *activity* region in between two *equilibrium states,* exactly like a river and its two banks. The equilibrium states are like the banks of the river, while the river represents the activity region.

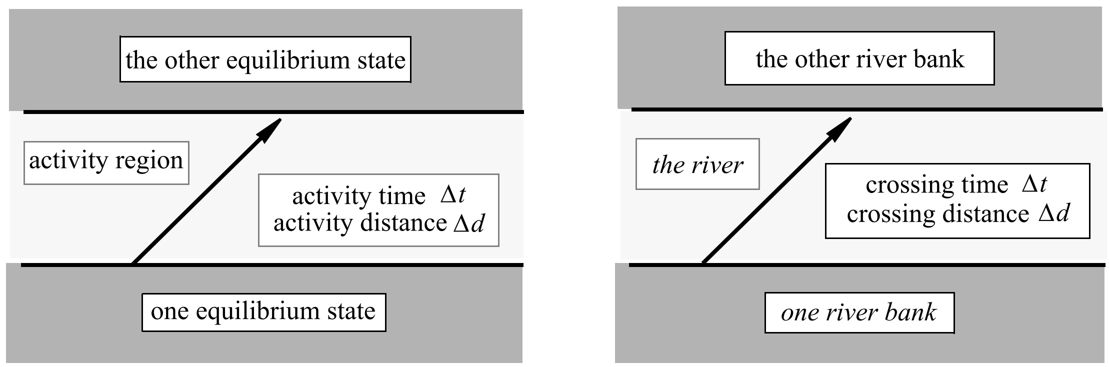


Fig (1) . The Solid and Fluid States

The time for which the system dwells in the activity region is Δt. Normally Δt is a small interval of time.

It should be pointed out that, in crossing the activity region, some distance must also be traversed. The (linear) distance thus involved, is also mentioned in the above two cases.

An illustration called "The Activity-Inactivity Story" is given at the end of the chapter. It shows some salient features of what has been discussed above and should be useful.

3-G-v How Do You Get to the Other Side?

The answer is *force*, *net force* to be exact. A net force acts on the system and Voila!

We are there.

We all know what a *force* is. The scientific concept of force is no different from its everyday concept. We use *force* numerous times every day. From raising our eyebrows to pushing a car (when it misbehaves), every action requires the application of a force.

3-H-i Revisiting Chapter One: The Purpose of "Physics"

In Chapter One, it was stated that the purpose of physics is to explain and/or determine the physical behavior of things in regard to their past, present and future. Having familiarized ourselves with the basic concepts (the infra-structure), we are now in a position to tell you how the said objectives can be achieved.

(a) To explain the *past* or the *future* of things, we shall determine one equilibrium state from a knowledge of the other equilibrium state, using the laws of physics. One equilibrium state will serve as *one* bank of the river, and the other, as the *other*.

(b) To explain the *present* of things, we shall analyze *that* equilibrium state itself.

3-H-ii The Two Aspects of Getting to the Other Side

What two aspects? Are you crazy? You just cross the river and that's all that matters.

Not exactly. If you were to plan the crossing (i.e. if you are a physicist), you would be concerned in knowing (i) the time it would take you to go across, and (ii) the distance you would travel through. Even though we will just cross the river, the two concerns have phenomenal consequences on the way we do physics. The extent of the impact of these consequences is beyond our comprehension (at this time).

To begin with let me just say that when we are investigating the *time* needed to get to the other side, we least care what distance we cover. We just want to know for what *time* (getting paid *by the hour*?) did this *net force* act upon the system. Likewise when we are investigating the *distance* covered in getting there, we least care what time we spend on the way. We just want to know for what *distance* (getting paid *by the mile?*) did this *net force* act on the system.

The first one of these, leads to what is commonly known as the *force approach* of doing physics, while the second one is mysteriously known as the *energy approach* of doing physics; even though it is *exactly* the same *net force* that acted upon the system in the *force approach*.

Things are different when it comes to the study of the *present*. In this case we have only one equilibrium state (no river to cross, shall we say?) and no *net force* either. We study or analyze the given equilibrium state itself. We remain sitting on one bank and keep pondering how come we are just sitting here, doing nothing?

3-H-iii Understanding the Phenomenal Consequences.

(i) The Force Approach

Force approach is based on a law, called the *Impulse-Momentum Theorem* (or: Newton's Second Law of Motion*)*. We travel *through* the terrain of the activity region that lies between the two equilibrium states. In our analogy, we would hire a boat and travel across the river, monitoring the motion with respect to time. Because of the active involvement of *time* in the process, it will be correct to say that:

The force approach is time dependent

The emphasis is on the *activity* region and not on the equilibrium states. We shall reproduce Fig (1) here to depict the Force Approach of doing physics.

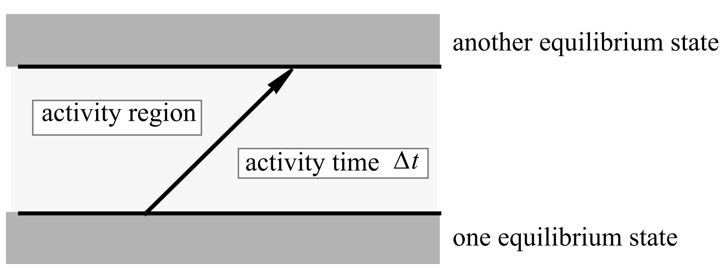


Fig (2) The Force Approach

To some extent we are like a taxi driver. We pick up passengers from the outside of one door and drop them off at the outside of another door. We do not wish to know *what is behind those doors, and* we do not wish to know *who the passengers are*. We just concern ourselves with driving the taxi and know that *we are paid by the hour!*

(ii) The Energy Approach

Like the concept of *force*, we are also quite at ease with the concept of *energy.* And again, like the concept of force, the scientific concept of energy is no different from our everyday concept of energy. In order to carry out our daily routine of work, we need energy. When our energy reserves get depleted, we feel tired. A motor car needs energy in the form of gasoline. So we fill up the tank and the car takes us to places.

Energy approach is based on a theorem, called the *Work-Energy Theorem*. It is *very* interesting to note that this theorem is an exact analog of the *Impulse-Momentum Theorem*. We determine the total energy of the initial equilibrium state and then do the same for the final equilibrium state when we get there. The Work-Energy Theorem does the rest. It should be carefully noted that all we want to know about the activity region is that for what (linear) distance(s) did the force(s) do work. Any *time* related information is inconsequential. Likewise any *time* related inquiries are not attended to. The total inconsequentiality of time, leads us to state:

The energy approach is time independent.

The emphasis here is on the two equilibrium states and not on the activity region. In this respect, the energy approach is exactly opposite of the force approach. May be we are not the taxi driver any more. We are the passengers for a change. We know *where we are coming from* and we know *where we are headed to.* We are not concerned with the taxi, the road or the traffic conditions. We also know that *we are paid by the mile*. Imagine being despatched to attend a conference.

A word about *patent rights*. The concept of *equilibrium* (and not just the name) is an *exclusive* property of the concept of force. The use of the word *equilibrium* is illegal in the *energy* land. Expressed otherwise, we can say that *energy* land *does not recognize* the concept of *equilibrium*. But this is no big deal. When in the energy territory, we simply change the terminology. Instead of the term *equilibrium* state we use the term *steady* state. There is not an iota of difference between the two.

The above discussion is subject to some constraints and restrictions. These need not be elaborated at this time. In essence, the above statements are valid. We shall reproduce Fig (1) here to depict the energy approach of doing physics.

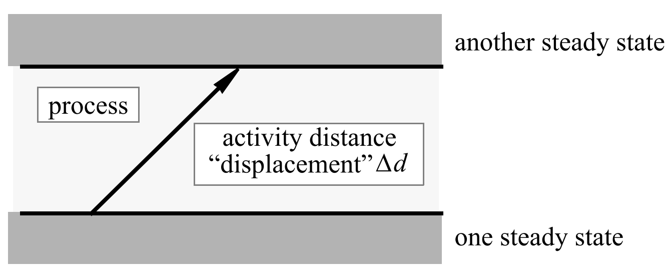


Fig (3) he Energy Approach

3-I-i Defining “Center of Mass”

In Chapter One we introduced the *center of mass (CM* for short*)* as a basic characteristic of solids. We shall elaborate upon this concept now.

The *CM* of an object is a geometrical point at which the object can be balanced. Recall the example of the umbrella from Chapter One. The entire mass of the object is said to be concentrated at this geometrical point and the rest of the object supposedly has no mass. The *CM* may not actually be in the body of the object, in which case it would be located somewhere in space in the neighborhood of the object. We wish to remind you that a geometrical point has no dimensions and is, therefore, a vanishingly small (infinitesimal) geometrical point.

3-I-ii *The Anatomy of the "Centers of Mass"*

The mass of an object is distributed symmetrically around its *CM*.

To understand exactly what we mean by *symmetrical distribution*, consider a three-dimensional object (a chair, for example). Let it be enclosed in a sphere with the center of the sphere coinciding with the *CM* of the object. Let the sphere be divided into an even number of identical cones, such that to every cone there will correspond a conjugate cone, located diametrically opposite to it. The cone and its conjugate cone may not have equal masses. *Symmetrical distribution* then means that the effect of mass of one cone on the *CM*, will be completely neutralized by the effect of the mass of the conjugate cone on the *CM*. The *effect of mass* arises from the earth's pull on the cones. Again, the cones may all have different masses but the sum of masses of all cones will equal the mass of the object. The sphere should be large enough in size to enclose the object; even though the object may not *fill* the sphere. It will be pointless, however, to choose a sphere larger than needed, but it will still be an acceptable sphere.

If the object is two-dimensional, (its thickness is much smaller than its length and width, such as a sheet of irregular length and width) then we may enclose it in a circular cake-like enclosure, with the center of the enclosure coinciding with the *CM* of the object. This enclosure can be divided into an even number of identical sectors, such that to every sector there will correspond a conjugate sector, located diametrically opposite to it. The sector and its conjugate sector may not have equal masses The effect of mass of one sector on the *CM*, will be completely neutralized by the effect of the mass of the conjugate sector, on the *CM*. The *effect of mass* arises from the earth's pull on the sectors. Again, the sectors may all have different masses but the sum of masses of all sectors will equal the mass of the object. The enclosure should be large enough in size to enclose the object; even though the object may not *fill* the enclosure. It will be pointless, however, to choose an enclosure larger than needed, but it will still be an acceptable enclosure.

If the object is one-dimensional (its length far exceeds its width and thickness), such as a baseball bat, a hammer or a meter-stick, then its *CM* will lie somewhere on a line along its length, dividing the object into two parts of equal or unequal lengths. The effect of mass of each length on the center of mass will be equal and opposite. The two lengths may not have equal masses but the sum of their masses will equal the mass of the object.

For objects with *uniform* mass distributions and of *symmetrical* shape and size, their centers of mass will be their geometrical centers. In this case, all cones of a 3-D object, all sectors of a 2-D object and both segments of a 1-D object will have equal masses.

As has been stated before, the *CM* of an object may not necessarily be *in* the body of the object. The *CM* of a hollow sphere is the geometrical center of the sphere and is thus not *in* the body of the object. As another example, consider a coffee cup. It is well known that the *CM* of a cup of coffee is in the coffee (and not in the body of the cup). Another interesting example is that of an athlete executing a high jump whose *CM* never makes the high jump; as the athlete's body passes over the bar, his *CM* passes under the bar.

3-I-iii *The "Center of Mass" is for Real*

The *CM* of an object is **not an imaginary** point. It really does exist. If you suspend an object from a cord or rope and draw a vertical line (along the cord) that passes through the body of the object then the center of mass must lie somewhere on this line. To pin point the *CM*, suspend the object by tying the cord at a different part of the object and let it hang. Draw a second vertical line. The *CM* must lie on this line as well. Since there is only one *CM* and it lies on both lines, it must be the point of intersection of the two lines. We may try some more hangings of the object and draw vertical lines for each one of them. It will be found that all these lines intersect at just *one* point, *the center of mass* of the object! This is shown in Fig (4) below.

It will probably be difficult (though not impossible) to apply this technique to find the *CM* of 3-D objects such as (among other things) a fruit tart or an ice cream cone. You will be well advised not to try to find their centers of mass. Just gobble them up.

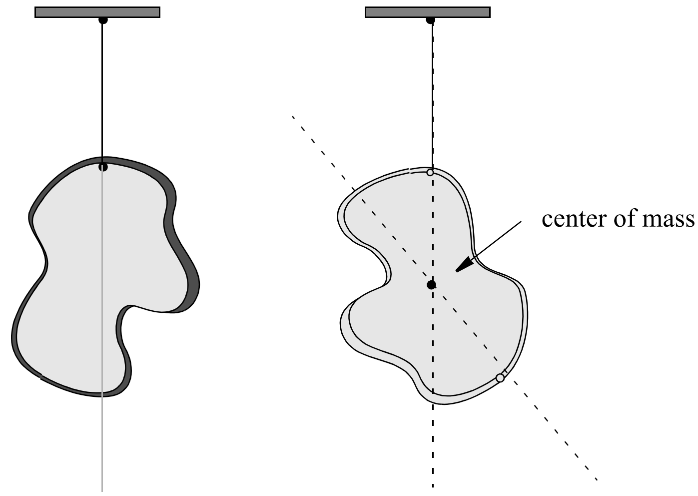


Fig (4) The Center of Mass of an Object

3-I-iv Center of Mass as "Universal Equalizer"

The *CM* of an object *represents* the entire object. We assume (**now *this* is imagination**) that all the mass of the object is concentrated at this point and hence the rest of the body is of no consequence. An entire body can then be effectively represented just by its *CM*. The *CM* will be all that we need and care for; driving the rest of the body into oblivion. The infinitesimally sized *CM* of an object representing the whole object (no matter how large or how small) has sparked the term *particle*. It is, in fact, for this reason that we use the word *particle* for objects and systems-of-objects of all shapes and sizes. Fig (5) shows the role of the *CM* of objects, as the *Universal Equalizer*.

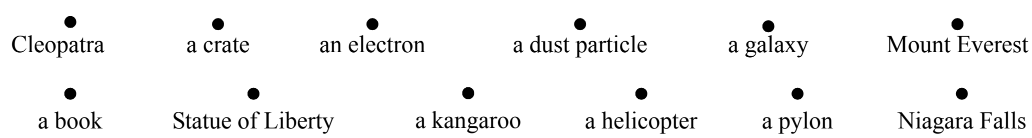


Fig (5) Centers of Mass of Selected Objects. (Shown Much Larger Than their Actual Sizes)

3-I-v The Role of the Center of Mass

The *CM* of an object is where every thing happens!

When we apply a force on an object, the force *effectively* acts at the *CM* of the object. To move a crate, we may hold it at its edge or attach a cord and apply a force of pull. Obviously we are applying the force at the corner, and if the rope were to break loose from the crate, the damage or deformation will occur at the corner of the crate. But if we ask you where the force is (or was) being applied *effectively*, the answer will be, *at the CM of the crate*.

Or consider a baseball bat that is launched in air in such a way that it spins as it cuts through air. Any object thrown in air always travels in a parabolic trajectory. The baseball bat is no exception; only that it is spinning as it is making its way through air. You will be interested to know that the *CM* of the bat automatically became the axis of its spinning motion. The bat spins around the *CM*, with the *CM itself* not spinning! Though not spinning, the *CM* does travel along the parabolic trajectory.

Did you notice? The bat as a whole is undergoing two kinds of motion simultaneously, whereas its *CM* (a part of its body, inside it) is undergoing only one kind of motion!

Does that make sense? Is it magic or what?

Or consider a shell that is fired from a cannon. As stated above, the *CM* of the shell will follow a parabolic trajectory. In fact the *CM* of the shell gets locked-on to the trajectory right at the instant of firing and, come rain, come shine, will not budge from it. If the shell were to explode in mid air, its pieces will fly off in different directions. The *CM* of *all* pieces will still be the *CM* of the original (un-exploded) shell. And what's more, as the pieces keep flying off in different directions with different speeds, the distances apart of the pieces and their speeds will change in such a way as to preserve the original *CM* on the original trajectory! It should be pointed out that in the beginning the *CM* of the shell was *in* the body of the shell but after the explosion it got relocated *outside* the body of the shell but it would still follow the original trajectory and would control the speeds and positions of all pieces so as to remain a sovereign and undisputed master.

It is correct to say that, for the center of mass, **the explosion never happened!**

Or consider Sheila who jumps from a diving board. Her *CM* gets locked-on to a parabolic trajectory. During the dive, she folds and unfolds herself and twists and turns in many different ways and forms (and wins an Olympic Gold). But was she in command of herself? The answer is no. It was her CM that controlled all her twists and turns in order for itself to execute a mathematically rigorously perfect parabolic trajectory. During her many foldings and unfoldings, if she becomes top heavy, her *CM* would pull the *whole* Sheila down so it (the *CM)* can remains on the trajectory. Likewise, if Sheila were to become bottom heavy, her *CM* will push her entire body up (against gravity), for the selfish reason of.....(you know what).

Such is life!

Or consider a tall dead tree, stills standing upright, but needing to be felled. When cut near its base, it tips over by rotating with its base as the axis of rotation. The top of the tall tree hits the ground with a big thud and one must remain at a safe distance in order not to get hurt. Now where did all the energy for the *big thud*, come from? No one pushed it. As energy cannot come from nowhere, it must have been present in the tree before its fall. The answer is that the energy was there all the time, living in the *CM* of the upright tree.

Or consider a collision of two (identical: same size, same mass) billiard balls on a pool table. It is a common experience that when one ball strikes a second stationary ball, head on, the first ball stops dead and the second ball inherits all the speed of the first ball (and runs away with the booty). This is in accordance with the laws of physics that govern collisions. Try doing this on a frictionless linear air track with two identical gliders, colliding head-on. You will be hopelessly disappointed. Why?

The laws of collision are valid only if the collision occurs along a line joining the centers of mass of the colliding objects! Billiard balls are spheres and as such their centers of mass are their geometrical centers. As the balls are of the same size, the collision does take place along the line joining their centers of mass. The predictions of the theory are found to be true. Gliders on an air-track are different. Because of their shape and size, the collision does not occur along the line of their centers of mass. The incident glider doesn't stop after collision and keeps moving forward, trailing behind the target glider.

So very disappointing!

3-I-vi Center of Mass & Stability

An object is stable *only* if its *CM* lies within its base. If the object is tilted slightly such that its *CM* remains within its base, the object will move back and re-seat itself wherever it was sitting before. But if it is tilted to an extent that the *CM* moves out of the base, the object will tip over (and may collapse in the process). The Leaning Tower of Pisa is stable because its *CM* is still within its base. If it were to lean to an extent that its *CM* slides out of its base, it will collapse immediately. An object placed flat on the floor or table is in a stable condition. To topple it about an edge, we must tilt it to the extent that its *CM* slides out of its base. A top heavy box will topple for a smaller tilt angle whereas a bottom heavy box will have to be tilted through a much larger angle. For this reason, trees must grow in such a way as to keep their centers of mass within their (relatively small) bases.

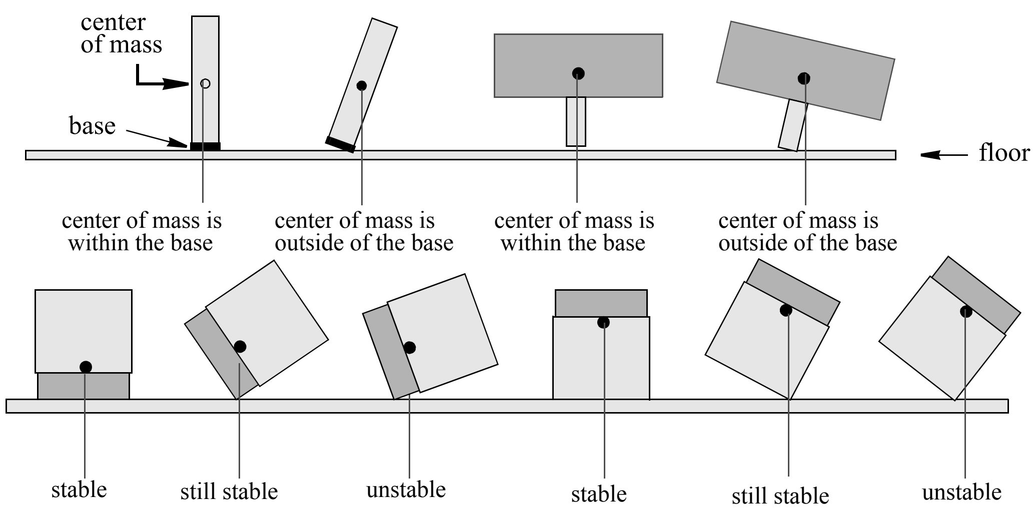


Fig (6) Center of Mass & Stability

3-J-i When Do We Use Physics?

As an epilogue to the discussions in the introductory chapters, we would like to tell you that, in general, one needs physics for activity regions only. As long as a system stays in a natural state, there is nothing to solve for and the services of a physicist may not be required. The exception, however, is the study of the anatomy of a natural state itself

The same is generally true of physicians. Usually one visits a physician when one is sick. The state of sickness is comparable to a fluid state (activity region) in between two rock solid (natural) states of good health. In general, the state of sickness (the activity region) is short lived. Occasionally, however, we do consult our physicians for a *general* check-up.

The Activity - Inactivity Story

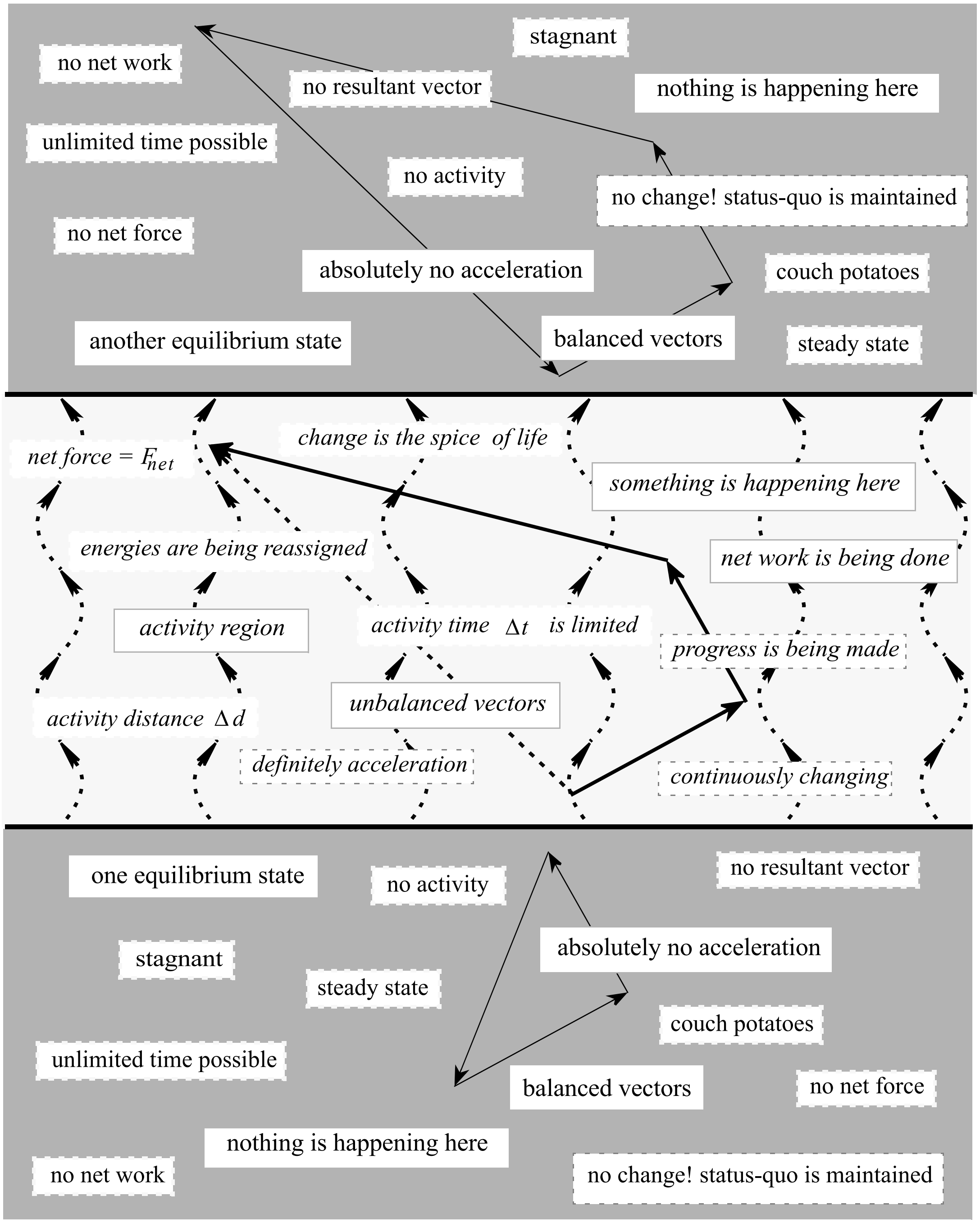
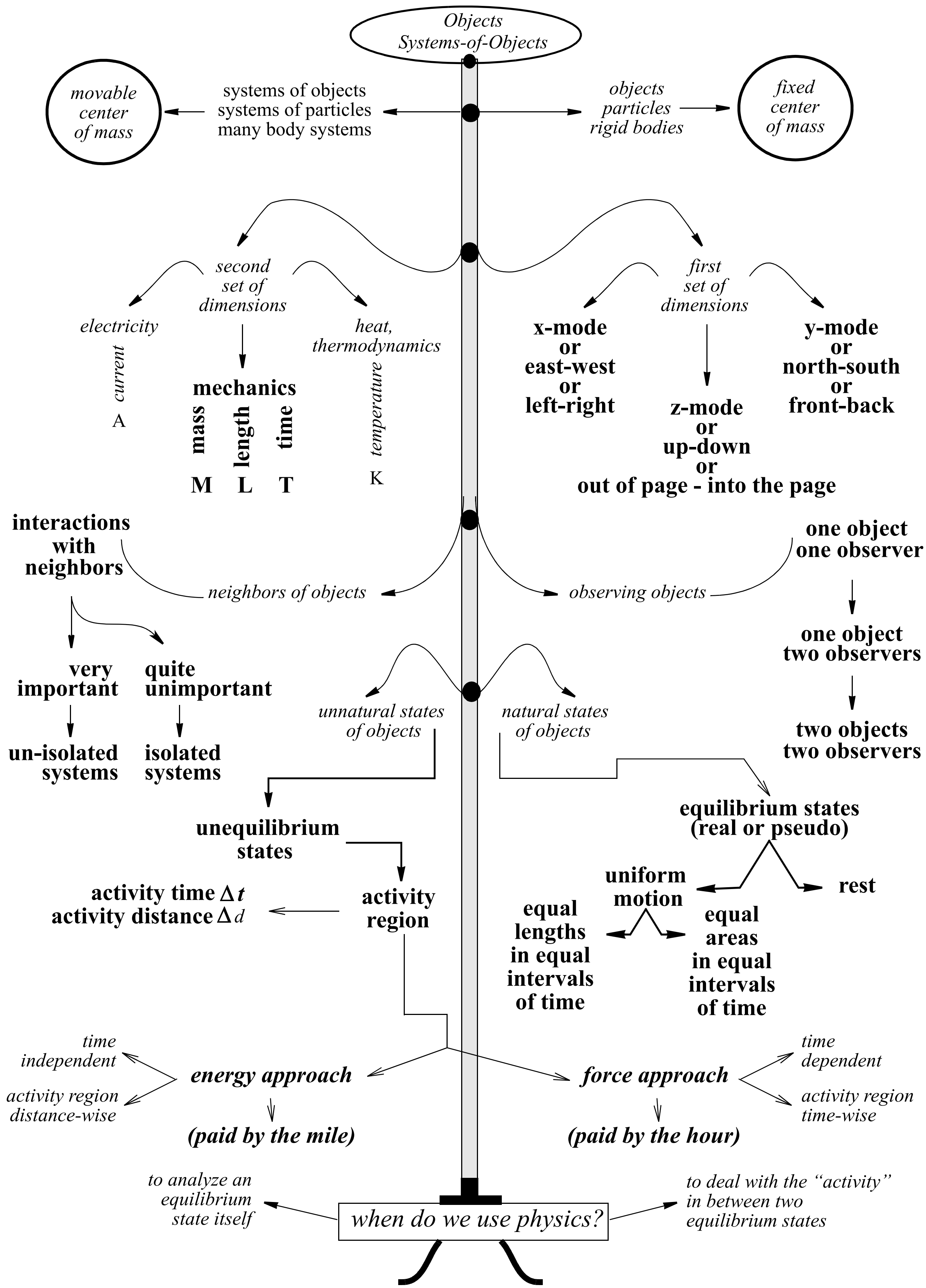


Fig (7) The Activity - Inactivity Story

3-J-ii A Summary


Objects
Systems-of-Objects
movable center of mass
systems of objects
systems of particles
many body systems
objects
particles
rigid bodies
fixed center of mass
second set of dimensions
electricity
current
A
mechanics
mass
length
time
M L T
heat, thermodynamics
temperature
K
first set of dimensions
x-mode or east-west or left-right
z-mode or up-down or out of page - into the page
y-mode or north-south or front-back
interactions with neighbors
neighbors of objects
observing objects
one object one observer
one object two observers
two objects two observers
very important
quite unimportant
un-isolated systems
isolated systems
unnatural states of objects
natural states of objects
unequilibrium states
equilibrium states (real or pseudo)
uniform motion
rest
activity time Δt
activity distance Δd
activity region
equal lengths in equal intervals of time
equal areas in equal intervals of time
time independent
activity region distance-wise
energy approach
(paid by the mile)
force approach
(paid by the hour)
time dependent
activity region time-wise
to analyze an equilibrium state itself
when do we use physics?
to deal with the "activity" in between two equilibrium states