THE FOURTH DAY

SAGREDO. I do not know whether you are really arriving later than usual for our accustomed discussion or whether it just seems so to me because of my desire to hear Salviati's thoughts on such an interesting matter. I have been watching through the window for a long time, hoping from one moment to the next to see the gondola come into view which I sent to fetch you.

SALV. I believe it is only your imagination that has made the time drag, rather than any tardiness on our part. But in order not to stretch it still further it will be good for us to get to the matter in hand without wasting any more words.

Let us see, then, how nature has allowed (whether the facts are actually such, or whether at a whim and as if to play upon our fancies) -- has allowed, I say, the movements that have long been attributed to the earth for every reason except as an explanation of the ocean tides to be found now to serve that purpose too, with equal precision; and how, reciprocally, this ebb and flow itself cooperates in confirming. the earth's mobility. Up to this point the indications of that mobility have been taken from celestial phenomena, seeing that nothing which takes place on the earth has been powerful enough to establish the one position any more than the other. This we have already examined at length by showing that all terrestrial events from which it is ordinarily held that the earth stands still and the sun and the fixed stars are moving would necessarily appear just the same to us if the earth moved and the others stood still. Among all sublunary things it is only in the element of water (as something which is very vast and is not joined and linked with the terrestrial. globe as are all its solid parts, but is rather, because of its fluidity, free and separate and a law unto itself) that we may recognize some trace or indication of the earth's behavior in regard to motion and rest. After having many times examined for myself the effects and events, partly seen and partly heard ; from other people, which are observed in the movements of the water; after, moreover, having read and listened to the great follies which many people have put forth as causes for these events, I have arrived at two conclusions which were not lightly to be drawn and granted. Certain necessary assumptions having been made, these are that if the terrestrial globe were immovable, the ebb and flow of the oceans could not occur naturally; and that when we confer upon the globe the movements just assigned to it, the seas are necessarily subjected to an ebb and flow agreeing in all respects with what is to be observed in them.

SAGR. The proposition is crucial, both in itself and in what follows as a consequence; therefore I shall be so much the more attentive in listening to its explanation and verification.

SALV. In questions of natural science like this one at hand, I a knowledge of the effects is what leads to an investigation and discovery of the causes. Without this, ours would be a blind journey, or one even more uncertain than that; for we should not know where we wanted to come out, whereas the blind at least know where they wish to arrive. Hence before all else it is necessary to have a knowledge of the effects whose causes we are seeking. Of those effects you, Sagredo, must be more fully and surely informed than I am, since besides being born in Venice and having long resided here where the tides are famous for their size, you have also sailed to Syria, and, having a clever and curious mind, you must have made many observations. But I, who have only been able to observe for rather a short time what happens here at this end of the Adriatic Gulf, and in our lower sea on the shores of the Tyrrhenian, must often depend upon what others tell me -- which, being for the most part not in good agreement and accordingly rather unreliable, may contribute confusion rather than confirmation to our reflections.

Still, from those accounts which we are sure of, and which happen to cover the principal events, it seems to me possible to arrive at the true and primary causes. I do not presume to be able to adduce all the proper and sufficient causes of those effects which are new to me and which consequently I have had no chance to think about; what I am about to say, I

propose merely as a key to open portals to a road never before trodden by anyone, in a firm hope that minds more acute than mine will broaden this road and penetrate further along it than I have done in my first revealing of it. And though in other seas remote from us events may take place which do not occur in our Mediterranean, nevertheless the reason and the cause which I shall produce will still be true, provided that it is verified and fully satisfied by the events which do take place in our sea; for ultimately one single true and primary cause must hold good for effects which are similar in kind. I shall, then, tell you the story of the effects which I know to exist, and assign to them the cause that is believed by me to be true; and you, gentlemen, shall produce others noticed by you in addition to these of mine, and then we shall see whether the cause I am about to adduce can account for them also.

I say, then, that three periods are observed in the flow and ebb of the ocean waters. The first and principal one is the great

I say, then, that three periods are observed in the flow and ebb of the ocean waters. The first and principal one is the great and conspicuous daily tide, in accordance with which the waters rise and fall at intervals of some hours; these intervals in the Mediterranean are for the most part about six hours each -- that is, six hours of rising and six more of falling. The second period is monthly, and seems to originate from the motion of the moon; it does not introduce other movements, but merely alters the magnitude of those already mentioned, with a striking difference according as the moon is full, new, or at quadrature with the sun. The third period is annual, and appears to depend upon the sun; it also merely alters the daily movements by rendering them of different sizes at the solstices from those occurring at the equinoxes.

We shall speak first about the diurnal period, as it is the principal one, and the one upon which the actions of the moon and the sun are exercised secondarily in their monthly and annual alterations. Three varieties of these hourly changes are observed; in some places the waters rise and fall without making any forward motion; in others, without rising or falling they move now toward the east and again run back toward the west; and in still others, the height and the course both vary. This occurs here in Venice, where the waters rise in entering and fall in departing. They do this at the end of a gulf extending east I and west and terminating on open shores where the water '. has room to spread out upon rising; if their course were interrupted by mountains or by very high dikes, they would rise and sink against these without any forward motion. Elsewhere the water runs to and fro in its central parts without changing height, as happens notably in the Straits of Messina between Scylla and Charybdis, where the currents are very swift because of the narrowness of the channel. But in the open Mediterranean and around its islands, such as the Balearics, Corsica, Sardinia, Elba, Sicily (on the African side), Malta, Crete, etc., the alterations of height are very small but the currents are quite noticeable, especially where the sea is restrained between islands, or between these and the continent.

Now it seems to me that these actual and known effects alone, even if no others were to be seen, would very probably persuade anyone of the mobility of the earth who is willing to stay within the bounds of nature; for to hold fast the basin of the Mediterranean and to make the water contained within it behave as it does surpasses my imagination, and perhaps that of anyone else who enters more than superficially into these reflections.

SIMP. These events, Salviati, did not just commence; they are very ancient, and have been observed by innumerable men, many of whom have contrived to give one reason or another to account for them. Not far from here there is a great Peripatetic who gives for them a cause recently dredged out of one of Aristotle's texts which had not been well understood by his interpreters. From this text, he deduces that the true cause of these movements stems from nothing else but the various depths of the seas. The deepest waters, being more abundant and therefore heavier, . expel the waters of lesser depth; these, being raised up, then try to descend, and from this continual strife the tides are derived.

Then there are many who refer the tides to the moon, saying that this has a particular dominion over the water. Lately a certain prelate has published a little tract wherein he says that the moon, wandering through the sky, attracts and draws up toward itself a heap of water which goes along following it, so that the high sea is always in that part which lies under the moon. And since when the moon is below the horizon, this rising nevertheless returns, he tells us that he can say nothing to account for this effect except that the moon not only retains this faculty naturally in itself, but in this case has also the power to confer it upon the opposite sign of the zodiac. Others, as I think you know, say that the moon also has power to rarefy the water by its temperate heat, and that thus rarefied, it is lifted up. Nor are those lacking who . . .

SAGR. Please, Simplicio, spare us the rest; I do not think there is any profit in spending the time to recount them, let

alone the words to refute them. If you should give assent to any of these or to similar triflings, you would be wronging your own judgment -- just when, as we know, it has been, much unburdened of error.

SALV. I am a little more easygoing than you, Sagredo, and I shall put in a few words for Simplicio's benefit if he thinks that some probability attaches to the things he has been telling us.

Simplicio, I say that waters which have their external surfaces higher expel those that are lower, but not that those which are deeper do so; and the higher waters, having driven away the lower, quickly come to rest and equilibrium. Your Peripatetic must believe that all the lakes in the world (which remain placid) and all the seas where the tide is imperceptible must have perfectly level beds; I was so naIve as to persuade myself that even if there were no other soundings, the Islands whIch rise above the water would be a very obvious indication of the unevenness of the bottoms. You might tell your prelate that the moon travels over the whole Mediterranean every day, but the waters are raised only at its eastern extremity and for us here at Venice.

As for those who make the temperate heat of the moon able to swell the water, you may tell them to put afire under a kettle of water, hold their right hands in this until I the heat raises the water a single inch, and then take them out to write about the swelling of the seas. Or ask them at least to show you how the moon rarefies a certain part. of the water and not the remainder, such as this here at Venice, but not that at Ancona, Naples, or Genoa.

Let us just say that there are two sorts of poetical minds -- one kind apt at inventing fables, and the other disposed to believe them.

SIMP. I do not think that anyone believes fables when he knows them to be such; and as to the opinions about the cause of the tides (which are numerous), since I know that there is only one true and primary cause for one effect, I understand perfectly that at most one can be true, and all the rest must be false and fabulous. Perhaps the true one is not even among those which have been produced up to date. I rather believe this to be so, since it would be remarkable if the true cause should shed so little light as not to show through the darkness of so many false ones. But I must say, with that frankness which is permitted here among ourselves, that to introduce the motion of the earth and make it the cause of the tides seems to me thus far to be a concept no less fictitious than all the rest I have heard. If no reasons more agreeable to natural phenomena were presented to me, I should pass on unhesitatingly to the belief that the tide is a supernatural effect, and accordingly miraculous and inscrutable to the human mind -- as are so many others which depend directly upon the omnipotent hand of God.

SALV. You argue very prudently, and also in agreement with Aristotle's doctrine; at the beginning of his Mechanics; as you know, he ascribes to miracles all things whose causes are hidden. But I believe you do not have any stronger indication that the true cause of the tides is one of : those incomprehensibles than the mere fact that among all I things so far adduced as verae causae there is not one which we can duplicate for ourselves by means of appropriate artificial devices. For neither by the light of the moon or sun, nor by temperate heat, nor by differences of depth can we ever make the water contained in a motionless vessel run to and fro, or rise and fall in but a single place. But if, by simply setting the vessel in motion, I can represent for you without any artifice at all precisely those changes which are perceived in the waters of the sea, why should you reject this cause and take refuge in miracles?

SIMP. I shall have recourse to miracles unless you dissuade me from it by other natural causes than the motion of the containers of the waters of the sea. For I know that the latter containers do not move, the entire terrestrial globe being naturally immovable.

SALV. But do you not believe that the terrestrial globe could be made movable supernaturally, by God's absolute power?

SIMP. Who can doubt this?

SALV. Then, Simplicio, since we must introduce a miracle to achieve the ebbing and flowing of the oceans, let us make the earth miraculously move with that motion by which the oceans are naturally moved. This operation will indeed be as much simpler and more natural among things miraculous, as it is easier to make a globe turn around (which we see so many of them do) than to make an immense bulk of water go back and forth more rapidly in some places than in others; rise and fall, here more, there less, and in other places not at all, and to make all these variations within the same containing vessel. Besides, these are many miracles, while the other is only one. Add to this that the miracle of making the water move brings another miracle in its train, which ,is that of holding the earth steady against the impulses of the water. For these would be capable of making it vacillate first in one direction and then in the other, if it were not miraculously retained.

SAGR. Let us suspend judgment for a while as to the folly of the new opinion which Salviati wants to explain to us, Simplicio, and not be so quick to class it with those ridiculous older ones. As to the miracle, let us likewise have recourse to that only after we have heard arguments which are restricted within the bounds of nature. Though, indeed, to my mind all works of nature and of God appear miraculous.

SALV. That is the way I feel about it, and saying that the natural cause of the tides is the motion of the earth does not exclude this operation from being miraculous.

Now, returning to our discussion, I reply and reaffirm that it has never previously been known how the waters contained in our Mediterranean basin can make those movements which they are seen to make, so long as this basin and containing vessel rests motionless. What renders the matter puzzling is daily observed, as I am about to describe; therefore, listen carefully.

We are here in Venice, where the waters are now low; the sea is quiet, the air tranquil; the water is commencing to rise, and at the end of five or six hours it will have gone up ten spans or more. This rise is not made by the original water being rarefied, but by water newly arriving here -- water of the same kind as the original water, with the same salinity, the same density, the same weight. Ships float in it, Simplicio, without submerging a hair's-breadth further; a barrel of it weighs not a grain more or less than the same quantity of the other; it keeps the same coldness entirely unchanged; in short, it is water which has recently and visibly entered through the channels and mouths of the Lido.

Now you tell me how and whence it came here. Are there perchance hereabouts some abysses or openings in the bottom

Now you tell me how and whence it came here. Are there perchance hereabouts some abysses or openings in the bottom of the sea through which the earth draws in and expels the water, breathing like some immense and monstrous whale? If so, why does the water not rise likewise over a space of six hours at Ancona, Dubrovnik (Ragugia), and Corfu, where the increase is small or even imperceptible? Who will find a way to pour new water into an immovable vessel and have it rise only in one definite place and not in others?

Do you perhaps say that this new water is borrowed from the ocean, carried in through the Straits of Gibraltar? This will not remove the difficulties mentioned; it will only make them greater. In the first place, tell me what must be the course of that water which, entering by the strait, is conducted in six hours clear to the extreme coast of the Mediterranean, a distance of tWo or three thousand miles, and retraces the same space on its retUrn? What would become of the ships scattered about on the sea? And what of those in the strait, on a continual watery precipice of immense bulk, entering through a channel no more than eight miles wide -- a channel which must in six hours give passage to enough water to inundate a space hundreds of miles wide and thousands long? Where is the tiger or falcon that ever ran or flew with such speed? A speed, I mean, of 400 miles an hour or better.

It cannot be denied that there are currents running the length of the gulf, but they are so slow that a rowboat can outrun them, though not without losing headway. Besides, if this water comes in through the strait, there is another difficulty: How does it cause so much of a rise here, at so remote a place, without first raising the closer parts by a similar or greater amount? To sum up, I do not believe that either obstinacy or subtleness of wit could ever discover a reply to these difficulties and thereby be able to maintain the fixity of the earth against them, while remaining within natural limitations.

SAGR. So far I follow you very well, and I am anxiously waiting to hear how these marvels can take place unimpeded if we assume the motions already assigned to the earth.

SALV. As these effects must be consequences of the motions which belong naturally to the earth it is not only necessary that they encounter no obstacle or impediment, but that they follow easily. Nor must they merely follow easily; they must follow necessarily, in such a way that it would be impossible for them to take place in any other manner For such is the property and condition of things which are natural and true.

Having established, then, that it is impossible to explain the movements perceived in the waters and at the same time maintain the immovability of the vessel which contains them, let us pass on to considering whether the mobility of the container could produce the required effect in I the way in which it is observed to take place. Two sorts of .movement may be conferred upon a vessel so that the : water contained in it acquires the property of running first I toward one end and then toward the other, and rise and , sink there. The first would occur when one end is lowered I and then the other, for under those conditions the water, ~ running toward the depressed part, rises and sinks alternately at either end. But since this rising and sinking is I nothing but a retreat from and an approach toward the center of the earth, this sort of movement cannot be attributed to concavities in the earth itself as containing vessels of the waters, For such containers could not have parts I able to approach toward or retreat from the center of the ~ terrestrial globe by any motion whatever that might be assigned to the latter.

The other sort of motion would occur when the vessel was moved without being tilted, advancing not uniformly but with a changing velocity, being sometimes accelerated and sometimes retarded. From this variation it would follow that the water (being contained within the vessel but not firmly adhering to it as do its solid parts) would because of its fluidity be almost separate and free, and not compelled to follow all the changes of its container. Thus the vessel being retarded, the water would retain apart of the impetus already received, so that it would run toward the forward end, where it would necessarily rise. On the other hand, when the vessel was speeded up, the water would retain apart of its slowness and would fall somewhat behind while becoming accustomed to the new impetus, remaining toward the back end, where it would rise somewhat.

These effects can be very clearly explained and made evident to the senses by means of the example of those barges which are continually arriving from Fusina filled with water for the use of this city. Let us imagine to ourselves such a barge coming along the lagoon with moderate speed, placidly carrying the water with which it is filled, when either by running aground or by striking some obstacle it becomes greatly retarded. Now the water will not thereby lose its previously received impetus equally with the barge; keeping its impetus, it will run forward toward the prow, where it will rise perceptibly, sinking at the stern. But if on the other hand the same barge noticeably increases its speed in the midst of its placid course, then the water which it contains (before getting used to this and while retaining its slowness) will stay back toward the stern, where it will consequently rise, sinking at the prow. This effect is indubitable and clear; it may be tested experimentally at any time, and there are three things about it which I want you to note particularly.

The first is that in order to make the water rise at one extremity of the vessel, there is no need of new water, nor need the water run there from the other end.

The second is that the water near the middle does not rise or sink noticeably unless the course of the barge happens to be very fast to begin with, and the object struck or other hindrance which checks it is very strong and unyielding. In such an event this might not only make all the water run forward, but cause most of it to jump right out of the barge; the same would also happen if a very violent impulse were suddenly given to it when it was traveling very slowly. But if to a gentle motion of its own there were added a moderate retardation or acceleration, the parts in the middle (as I said) would rise and sink imperceptibly, and the other parts would rise the less according as they were closer to the middle, and the more according as they were farther from it.

The third thing is that whereas the parts around the center make little change as to rising or sinking with respect to the water at the ends, yet they run to and fro a great deal in comparison with the water at the extremities.

Now, gentlemen, what the barge does with regard to the water it contains, and what the water does with respect to the barge containing it, is precisely the same as what the Mediterranean basin does with regard to the water contained within

it, and what the water contained does with respect to the Mediterranean basin, its container. The next thing is for us to prove that it is true, and in what manner it is true, that the Mediterranean and all other sea basins (in a word, that all parts of the earth) move with a conspicuously uneven motion, even though nothing but regular and uniform motions may happen to be assigned to the globe itself.

SIMP. At first sight this looks like a great paradox to me, though I am no mathematician or astronomer. If it is true that the motion of the whole maybe regular, and that of the parts which always remain attached to it may be irregular, then this is a paradox destroying the axiom which affirms tandem esse rationem totius et partium.

SALV. I shall prove my paradox, Simplicio, and then leave to you the burden of either defending the axiom against it or of bringing the two into accord. My demonstration will be brief and easy; it will depend upon things already dealt with at length in our past conversations, without introducing the slightest word to make it favor the ebb and flow.

We have already said that there are two motions attributed to the terrestrial globe; the first is annual, made by its center along the circumference of its orbit about the ecliptic in the order of D the signs of the zodiac (that is, from west to east), and the other is made by the globe itself revolving around its own center in twenty-four hours (likewise from west to east) around an axis which is somewhat tilted, and not parallel to that of its annual revolution. From the composition of these two motions, each of them in itself uniform, I say that there results an uneven motion in the parts of the earth. In order for this to be understood more easily, I shall explain it by drawing a diagram.

Figure 28

First I shall describe around the center A the circumference of the earth's orbit BC, on which the point B is taken; and around this as center, let us describe this smaller circle DEFG, representing the terrestrial globe. We shall suppose that its center B runs along the whole circumference of the orbit from west to east; that is, from B toward C. We shall further suppose the terrestrial globe to turn around its own center B from west to east, in the order of the points D, E, F, G, during a period of twenty-four hours. Now here we must carefully note that when a circle revolves around its own center, every part of it must move at different times with contrary motions. This is obvious, considering that when the part of the circumference around the point D is moving toward the left (toward E), the opposite parts, around F, go toward the right (toward G); so that when the point D gets to F, its motion will be contrary to what it was originally when it was at D. Moreover, in the same time that the point E descends, so to speak, toward F, G ascends toward D. Since this contrariety exists in the motion of the parts of the terrestrial surface when it is turning around its own center, it must happen that in coupling the diurnal motion with the annual, there results an absolute motion of the parts of the surface which is at one time very much accelerated and at another retarded by the same amount. This is evident from considering first the parts around D, whose absolute motion will be very swift, resulting from two motions made in the same direction; that is, toward the left. The first of these is part of the annual motion, common to all parts of the globe; the other is that of this same point D, carried also to the left by the diurnal whirling, so that in this case the diurnal motion increases and accelerates the annual motion.

It is quite the opposite with the part across from D, at F. This, while the common annual motion is carrying it toward the left together with the whole globe, is carried to the right by the diurnal rotation, so that the diurnal motion detracts from the annual. In this way the absolute motion -- the resultant of the composition of these tw0 is much retarded.

Around the points E and G, the absolute motion remains equal to the simple annual motion, since the diurnal motion acts upon it little or not at all, tending neither to left nor to right, but downward and upward. From this we conclude that just as it is true that the motion of the whole globe and of each of its parts would be equable and uniform if it were moved with a single motion, whether this happened to be the annual or the diurnal, so is it necessary that upon these two motions being

mixed together there results in the parts of the globe this uneven motion, now accelerated and now retarded by the additions and subtractions of the diurnal rotation upon the annual revolution.

Now if it is true (as is indeed proved by experience) that the acceleration and retardation of motion of a vessel makes the

contained water run back and forth along its length, and rise and fall at its extremities, then who will make any trouble about granting that such an effect may -- or rather, must -- take place in the ocean waters? For their basins are subjected to just such alterations; especially those which extend from west to east, in which direction the movement of these basins is made.

Now this is the most fundamental and effective cause of the tides, without which they would not take place. But the particular events observed at different times and places are many and varied; these must depend upon diverse concomitant causes, though all must have some connection with the fundamental cause. So our next business is to bring up and examine the different phenomena which may be the causes of such diverse effects.

The first of these is that whenever the water, thanks to some considerable retardation or acceleration of motion of its containing vessel, has acquired a cause for running toward one end or the other, it will not remain in that state when the primary cause has ceased. For by virtue of its own weight and its natural inclination to level and balance itself, it will speedily return of its own accord; and being heavy and fluid, it will not only return to equilibrium but will pass beyond it, pushed by its own impetus, and will rise at the end where first it sank. But it will not stay there; , by repeated oscillations of travel it will make known to us that it does not want the speed of motion it has received to be suddenly removed and reduced to a state of rest. It wishes this to be slowly reduced, abating little by little. In exactly this way we see that a weight suspended by a cord, once removed from the state of rest (that is, the perpendicular), returns to this and comes to rest by itself, but only after having gone to and fro many times, passing beyond this perpendicular position in its coming and going.

The second event to be noticed is that the reciprocations of movement just mentioned are made and repeated with greater or less frequency (that is, in shorter or longer times) according to the various lengths of the vessels containing the water. In the shorter space, the reciprocations are more frequent, and they are rarer in the longer, just as in the above example of the plumb bobs the reciprocations of those which are hung on long cords are seen to be less frequent than those hanging from shorter threads.

For the third remark, you must know that it is not only a greater or lesser length of vessel which causes the water to perform its reciprocations in different times, but a greater or less depth does the same thing. It happens that for water contained in vessels of equal length but of unequal depth, the deeper water will make its vibrations in briefer times, and the oscillations will be less frequent in the shallower.

Fourth, such vibrations produce two effects in water which are worthy of being noticed and observed carefully. One is the alternating rising and falling at either extremity; the other is the horizontal moving and running to and fro, so to speak. These two different motions inhere differently in different parts of the water, The extreme ends of the water rise and fall the most; the central parts do not move, up and down at all; and other parts, by degrees as they are nearer to the ends, rise and fall proportionately more than .those farther from the ends. On the other hand, the central parts move a great deal in that other (progressive) movement back and forth, going and returning, while the waters in the extreme ends have none of this motion -- except so far as they may in rising happen to go higher than their banks, and spill out of their original channel and container. But where the hindrance of the banks restrains them, they merely rise and fall; nor does this prevent the waters in the middle from running back and forth, as do the other parts in proportion, traveling the more or the less according as they are located farther from or closer to the middle.

The fifth particular event must be more carefully considered, because it is impossible for us to duplicate its effects by any practical experiment. It is this: In an artificial vessel like the barge mentioned previously, moving now more rapidly and again more slowly, the acceleration or retardation is always shared uniformly by the whole vessel and by each of its parts. Thus, for example, when the barge is checked in its motion, its forward parts are no more retarded than its after parts, but all share equally in the same retardation. The same happens in acceleration; that is, conferring some new cause of greater velocity upon the barge accelerates the bow in the same way as the stern. But in immense vessels, such as long sea bottoms (though these indeed are nothing more than cavities made in the solidity of the terrestrial globe), it nevertheless happens remarkably enough that their extremities do not increase and decrease in speed jointly, equally, and in the same

instant of time. For it may happen that when one extremity of such a vessel is greatly retarded in its motion by virtue of a composition of these two motions, annual and diurnal, the other extremity may be affected by and involved in even a very swift motion. For your easier comprehension, let us explain this by going back to the diagram previously drawn. Let us suppose a stretch of sea to be as long as one quadrant; the arc BC, for instance. Then the parts near B are, as I said before, in very swift motion because the two movements (annual and diurnal) are united in the same direction, and the parts near

C are at that time in retarded motion, since they lack the forward movement depending upon the diurnal motion. If we suppose, I say, a sea bottom as long as the arc BC, we shall see at once that its extremities are moving very unequally at a given time. A stretch of sea as long as a semicircle and placed in the position of the arc BCD will have exceedingly different speeds, since the extremity B would be in very rapid motion, Din very slow motion, and the parts in the middle around C in moderate motion. In proportion as these stretches of sea were shorter, they would participate less in this strange phenomenon of having their parts diversely affected at certain times of day by speed and by slowness of motion.

Figure 29

Now if in the first place we see experimentally that an acceleration and a retardation shared equally by all parts of the containing vessel may indeed be the cause of the contained water running back and forth, then what must we suppose would happen in a vessel so remarkably situated that a retardation and an acceleration of motion are conferred very unevenly upon its parts? Certainly we cannot help saying that there would necessarily be perceived still greater and more marvelous causes of commotions in the water, and stranger ones. And though to many people it may seem impossible for us to test the effects of such events in artificial devices and vessels, nevertheless this is not entirely impossible; I have a mechanical model in which the effects of these marvelous compositions of movements may be observed in detail. But so far as our present purpose is concerned, what we have grasped intellectually up to this point is sufficient.

SAGR. For my part, I understand well enough that this remarkable phenomenon must necessarily exist in the ocean beds, especially in those which extend a long distance east and west; that is, along the direction of the movements of the terrestrial globe. And as the phenomenon is in a certain sense undreamed of and without parallel among the movements it is possible for us to make, it is not hard for me to believe that it may produce effects which cannot be imitated in our artificial experiments.

SALV. These things being cleared up, it is now time to examine in all their diversity the particular events which are observed experientially in the ebbing and flowing of the waters. First, it cannot be hard for us to understand why it happens that in lakes, pools, and even in small seas there is no noticeable tide. There are two impelling reasons for this. One is that because of the shortness of their basins they acquire at different hours of the day varying degrees of speed, but with little difference occurring among all their parts; they are uniformly accelerated and retarded as much in front as behind; that is, to the east as to the west. And they acquire such alterations, moreover, little by little, and not through the opposition of a sudden obstacle and hindrance, or a sudden and great acceleration in the movement of the containing vessel. The latter, with all its parts, becomes slowly and equally impressed with the same degree of velocity, and from this uniformity it follows that the contained water also receives the same impressions with little resistance or hesitation. Consequently the signs of rising and falling or of running to one extremity or the other are exhibited only obscurely. This effect is also clearly seen in small artificial vessels, in which the contained water is impressed with the same degrees of speed, whenever the acceleration or retardation is made in slow and uniform increments. But in the basins of oceans which extend a great distance from east to west, the acceleration or retardation is much more noticeable and uneven when one extremity of them is in a very retarded motion and the other is moving quickly.

The second reason is the reciprocal oscillation of the water instituted by the impetus already received from the motion of its container, which oscillation (as we have remarked) makes its vibrations with high frequency in small vessels. There inheres in the terrestrial movements a cause for conferring a movement upon the waters only from one twelve-hour period to another, since only once a day is the movement of the containing vessel exceedingly accelerated or retarded.. Now this second cause depends upon the weight of the water, which seeks to restore it to equilibrium, and it produces oscillations of one, two, or three hours, and so on, according to the shortness of the vessel. Thus the whole movement becomes entirely insensible upon this one being combined with the first, which even by itself remains very small for small vessels. For the primary cause, which has a period of twelve hours, will not have finished impressing its disturbance when overtaken and reversed by this second one depending upon the weight of the water and having a vibration time of one, two, three, or four hours, and so on, according to the shortness and depth of the basin. Acting contrary to the first cause, this perturbs and removes that without ever allowing it to attain the height, or even the average of its motion. Any evidence of ebbing or flowing is entirely annihilated by this conflict, or is very much obscured. I say nothing of the continual changing of the wind, which by disquieting the water would not permit us to be sure of some very small rising or falling, of half an inch or less, which might actually belong to the basins and containers of bodies of water no more than one degree or so in length.

Now, secondly, I shall resolve the question why, since there resides in the primary principle no cause of moving the waters except from one twelve-hour period to another (that is, once by the maximum speed of motion and once by its maximum slowness), the period of ebbing and flowing nevertheless commonly appears to be from one six-hour period to another. Such a determination, I say, can in no way come from the primary cause alone. The secondary causes must be introduced

Such a determination, I say, can in no way come from the primary cause alone. The secondary causes must be introduced for it; that is, the greater or lesser length of the vessels and the greater or lesser depth of the waters contained in them. These causes, although they do not operate to move the waters (that action being from the primary cause alone, without which there would be no tides), are nevertheless the principal factors in limiting the duration of the reciprocations, and operate so powerfully that the primary cause must bow to them. Six hours, then, is not a more proper or natural period for these reciprocations than any other interval of time, though perhaps it has been the one most generally observed because it is that of our Mediterranean, which has been the only place practicable for making observations over many centuries. Even so, this period is not observed everywhere in it; in some of the narrower places, such as the Hellespont and the Aegean, the periods are much briefer, and they are also quite variable among themselves. Some say it was because of these differences and the incomprehensibility of their causes to Aristotle that he, after observing them for a long time from some cliffs of Euboea (Negroponte), plunged into the sea in a fit of despair and willfully destroyed himself.

In the third place we shall see very readily the reason why a sea like the Red Sea, although very long, is nevertheless quite devoid of any tide. This is so because its length does not extend from east to west, but runs from southeast to northwest. The movements of the earth being from west to east, the impulses of the water are always aimed against the meridians and not from one parallel to another. Hence in seas which extend lengthwise toward the poles and are narrow in the other direction, there is no cause of tides -- unless it is that of sharing those of some other sea with which they may communicate and which is subject to large movements.

We can very easily understand, in the fourth place, the reasons why the ebbing and flowing are greatest at the extremities of gulfs as to rising and falling of the waters, and least in the middle parts. Daily experience shows us this here in Venice, sitUated at the end of the Adriatic, where the difference commonly amounts to as much as five or six feet; but in parts of the Mediterranean distant from the extremities such changes are very small; as at the islands of Corsica and Sardinia, and on the coasts at Rome and Leghorn, where they do not exceed half a foot. We understand also why, on the other hand, where the rising and falling are small, the running to and fro is large. It is a simple thing, I say, to understand the cause of these events, because we have examples of them easily observable in all sorts of artificially manufactured vessels, in which the same effects are seen to follow naturally when we move them unevenly; that is, now accelerating and now retarding them.

Let us consider further, in the fifth place, how a given quantity of water moving slowly in a spacious channel must run very impetuously when it has to pass through a narrow place. From this we shall have no difficulty in understanding the cause of the great current which is created in the narrow channel that separates Calabria from Sicily. For all the water pent up by the extensive island and the Ionian Gulf in the eastern part of the sea, though because of the spaciousness there it descends slowly toward the west, yet upon being restrained in the Straits of Messina between Scylla and Charybdis, it drops rapidly and makes a great agitation. Something similar to this, but greater, is said to occur between Africa and the great island of Madagascar (San Lorenzo), when the waters of the two great Indian and South Atlantic (Etiopico) oceans, in whose midst this lies, must be restricted in their running into the still smaller channel between it and the coast of South Africa. The currents in the Straits of Magellan must be extremely great, communicating between the South Atlantic and the South Pacific oceans.

In the sixth place, in order to give reasons for some more recondite and curious events that are observed in this field, it remains now for us to make another important reflection upon the two principal causes of the tides, thereafter compounding them and mixing them together. The first and simplest of these, as I .have often said, is the definite acceleration and retardation of the parts of the earth from which the waters receive a determinate period, running toward the east and returning to the west within a space of twenty-four hours. The other depends upon the water's own weight, which, once moved by the primary cause, tries then to restore itself to equilibrium by repeated oscillations which are not determinate as to one preestablished time alone, but which have differences of duration according to the different lengths and depths of the containers and basins of the oceans. In so far as they depend upon this second principle, some would flow and return in one hour, some in two, in four, in six, in eight, in ten, etc.

Now if we commence to add the first cause, which has an established period of twelve hours, to the second when it has for example a period of five, then it will sometimes happen that the primary and secondary causes agree in making their impulses both in the same direction; and in such a conjunction (or, so to speak, in such a unanimous conspiracy) the tides will be very great. At other times it happens that the primary impulse becomes in a certain sense contrary to that brought by the secondary; and in such encounters one impulse takes away what the other gives, so that the motion of the waters is weakened and the sea is reduced to a very peaceful and practically motionless state. At still other times, when the two principles are not in opposition nor yet entirely unified, they cause other variations in the rise and fall of the tides.

It may also happen that two very large seas which are in communication through some narrow channel are found to have, because of the mixture of the two principles of motion, a cause of flood in one at the very time the other is having the contrary movement. In this case extraordinary agitations are made in the channel through which they communicate, with

opposing motions and vortexes and most dangerous churnings, of which in fact we hear continual tales and accounts. From such discordant movements, depending not only upon different situations and lengths, but even more upon the differing depths of the communicating seas, there sometimes arise various disorderly and unobservable aquatic commotions whose causes have perturbed sailors very much, and still do, when encountered in the absence either of gusts of wind or other significant atmospheric changes which might account for them.

Now these disturbances of the air must be carefully taken into consideration with the other phenomena, and regarded as a third occasional cause capable of greatly altering our observations of effects dependent upon the primary and more essential causes. For there is no doubt that strong winds blowing continuously from the east, for instance, may sustain the waters, preventing their ebb. If then a second recurrence of the high tide, and even a third, is added at the established hours, the waters will swell up very high. In such away, sustained for several days by the force of the wind, they may be raised much more than usual, and make extraordinary floods. We must also take notice of another cause of movement, and this will be our seventh problem. This depends upon the great quantity of water from the rivers that empty into seas which are not vast, for which reason the water is seen to run always in the same direction in channels or straits through which such seas communicate, as happens in the Thracian Bosporus below Constantinople, where the water runs always from the Black Sea toward the Sea of Marmara (Propontide). For the Black Sea the principal causes of ebb and flow are not very effective, because of its shortness; while on the other hand very large rivers empty into it, and this great flow of water must be passed and disgorged through the strait, where the current is quite famous and is always toward the south. Moreover, we must take note that this strait or channel, though it is certainly very narrow, is not subjected to any such perturbations as the strait between Scylla and Charybdis; for the former has the Black Sea above it to the north, with the Sea of Marmara, the Aegean Sea, and the Mediterranean adjoining it to the south -- though over a long tract, and, as we have already noted, however long a sea may be from north to south, it is not subject to tides. But since the Sicilian strait is situated between parts of the Mediterranean, extending a great distance from west to east -- that is, with the tidal currents -- the agitations in it are very great. They would be still greater at the Gates of Hercules, if the Straits of Gibraltar were less open; and the currents in the Straits of Magellan are reported to be extremely strong.

This is all that occurs to me at present to tell you about the causes of this basic diurnal period of the tides, and of their various incidental phenomena. If anything is to be brought up in connection with these, it may be done now; then we may proceed to the other two periods, the monthly and the annual.

SIMP. I do not think it can be denied that your argument goes along very plausibly, the reasoning being ex suppositions, as we say; that is, assuming that the earth does move in the two motions assigned to it by Copernicus. But if we exclude these movements, all the rest is vain and invalid; and the exclusion of this hypothesis is very clearly pointed out to us by your own reasoning. Under the assumption of the two terrestrial movements, you give reasons for the ebbing and flowing; and vice versa, arguing circularly, you draw from the ebbing and flowing the sign and confirmation of those same two movements. Passing to a more specific argument, you say that on account of the water being a fluid body and not firmly attached to the earth, it is not rigorously constrained to obey all the earth's movements. From this you deduce its ebbing and flowing.

In your own footsteps, I argue the contrary and say: The air is even more tenuous and fluid than the water, and less affixed to the earth's surface, to which the water adheres (if for no other reason) because of its own weight, which presses its own much more than the very light air. Then so much the less should the air follow the movements of the earth; hence if the earth did move in those ways, we, its inhabitants, carried along at the same velocity, would have to feel a wind from the east perpetually beating against us with intolerable force. That such would necessarily follow, daily experience informs us; for if, in riding post with no more speed than eight or ten miles an hour in still air, we feel in our faces what resembles a wind blowing against us not lightly, just think what our rapid course of eight hundred or a thousand miles per hour would have to produce against air which was free from such motion! Yet we feel nothing of any such phenomenon.

SALV. To this objection, which seems so persuasive, I reply that it is true that the air is much more tenuous and much lighter than the water, and by its lightness is much less adherent to the earth than heavy and bulky water. But the consequence which you deduce from these conditions is false; that is, that because of its lightness, tenuity, and lesser adherence to the earth it must be freer than water from following the movements of the earth, so that to us who participate completely in those movements its disobedience would be made sensible and evident. In fact, quite the opposite happens. For if you will remember carefully, the cause of the ebbing and flowing of the water assigned by us consisted in the water not following the irregularity of motion of its vessel, but retaining the impetus which it had previously received, and not diminishing it or increasing it in the exact amount by which this is increased or diminished in the vessel. Now since disobedience to a new increase or diminution of motion consists in conservation of the original received impetus, that moving body which is best suited for such conservation will also be best fitted for exhibiting the effect that follows as a consequence of this conservation. How strongly water is disposed to preserve a disturbance once received, even after the cause impressing it has ceased to act, is demonstrated I to us by the experience of water highly agitated by strong winds.

Though the winds may have ceased and the airs become tranquil, such waves remain in motion for along time, as the sacred poet so charmingly sings: Qual l'alto Egeo, etc. The continuance of the commotion in this way depends upon the weight of the water, for as has been said on other occasions, light bodies are indeed much easier to set in motion than heavier ones, but they are also much less able to keep the motion impressed upon them, once the cause of motion stops. The air, being a thing that is in itself very tenuous and extremely light, is most easily movable by the slightest force; but it is also most inept at conserving the motion when the mover ceases acting.

As to the air that surrounds the terrestrial globe, I shall therefore say that it is carried around by its adherence no less than the water, and especially those parts of it which are contained in vessels, these vessels being plains surrounded by mountains. And we may much more reasonably declare that such parts are carried around, swept along by the roughness of the earth, than that the higher parts are swept along by the celestial motion as the Peripatetics assert.

What I have said so far seems to me to be an adequate reply to Simplicio's objection. But I want to give him more than satisfaction by means of a new objection and another reply, founded upon a remarkable experiment, and at the same time substantiate for Sagredo the mobility of the earth.

I have said that the air, and especially that part of it which is not above the highest mountains, is carried around by the roughness of the earth's surface. From this it seems to follow that if the earth were not uneven, but smooth and polished,

there would be no reason for its taking the air along as company, or at least for its conducting it with so much uniformity. Now the surface of this globe of ours is not all mountainous and rough, but there are very large areas that are quite smooth; such are the surfaces of the great oceans. These, being also quite distant from the mountain ranges that encirc1e them, appear not to have any aptitude for carrying along the air above them; and whatever may follow as a consequence of not carrying it ought therefore to be felt in such places.

SIMP. I also wanted to raise this same objection, which seems to me very powerful.

SALV. You may well say this, Simplicio, in the sense that from no such thing being felt in the air as would result from this globe of ours going around, you argue its immobility. But what if this thing that you think ought to be felt as a necessary consequence were, as a matter of fact, actually felt? Would you accept this as a sign and a very powerful argument of the mobility of this same globe?

SIMP. In that case it would not be a matter of dealing with me alone; for if this should happen and its cause were hidden from me, perhaps it might be known to others.

SALV. So no one can ever win against you, but must always lose; then it would be better not to play. Nevertheless, in order not to cheat our umpire, I shall go on.

We have just said, and will now repeat with some additions, that the air, as a tenuous and fluid body which is not solidly attached to the earth, seems to have no need of obeying the earth's motion, except in so far as the roughness of the terrestrial surface catches and carries along with it that part of the air which is contiguous to it, or does not exceed by any great distance the greatest altitude of the mountains. This portion of the air ought to be least resistant to the earth's rotation, being filled with vapors, fumes, and exhalations, which are materials that participate in the earthy properties and are consequently naturally adapted to these same movements. But where the cause for motion is lacking -- that is, where the earth's surface has large flat spaces and where there would be less admixture of earthy vapors -- the reason for the surrounding air to obey entirely the seizure of the terrestrial rotation would be partly removed. Hence, while the earth is revolving toward the east, a beating wind blowing from east to west ought to be continually felt in such places, and this blowing should be most perceptible where the earth whirls most rapidly; this would be in the places most distant from the poles and closest to the great circle of the diurnal rotation.

Now the fact is that actual experience strongly confirms this philosophical argument. For within the Torrid Zone (that is, between the tropics), in the open seas, at those w parts of them remote from land, just where earthy vapors are absent, a perpetual breeze is felt moving from the east with so constant a tenor that, thanks to this, ships prosper in their voyages to the West Indies. Similarly, departing from the Mexican coast, they plow the waves of the Pacific Ocean with the same ease toward the East Indies, which are east to us but west to them. On the other hand, voyages from the Indies eastward are difficult and uncertain, nor may they in any case be made along the same routes, but must be piloted more toward the land so as to find other occasional and variable winds caused by other principles, such as we dwellers upon terra firma continually experience. There are many and various reasons for the origin of such winds which we need not bother to bring up at present. These occasional winds blow indifferently toward all f parts of the earth, disturbing seas distant from the equator and bordered by the rough surface of the earth. This amounts to saying that such seas are subjected to those disturbances of the air which interfere with the primary current of air that would be felt continually, especially on the ocean, if such accidental disturbances were lacking.

Now you see how the actions of the water and the air show themselves to be remarkably in accord with celestial observations in confirming the mobility of our terrestrial globe.

SAGR. Yet in order to cap all this, I wish also to tell you one particular which seems to me to be unknown to you, yet which confirms this same conclusion. You, Salviati, have mentioned that phenomenon which sailors encounter in the tropics; I mean that constant wind blowing from the east, of which I have heard accounts from those who have made the voyage quite often. Moreover, it is an interesting fact that sailors do not call this a "wind," but have some other name for it

which slips my mind, taken perhaps from its even tenor. When they encounter it, they tie up their shrouds and the other cordage of the sails, and without ever again having any need to touch these, they can continue their voyage in security, or even asleep. Now this perpetual breeze has been known and recognized by reason of its blowing continuously without interruption; for if other winds had interrupted it, it would not have been recognized as a singular effect different from all the others. From this I may infer that the Mediterranean Sea might also participate in such a phenomenon, but that this escapes unobserved because it is frequently interrupted by other supervening winds. I say this advisedly, and upon very probable theories which occurred to me from what I had occasion to learn during the voyage I made to Syria when I went to Aleppo as consul of our nation. Keeping a special record and account of the days of departure and arrival of ships at the ports of Alexandria, Alexandretta, and here at Venice, I discovered in these again and again that, to my great interest, the returns here (that is, the voyages from east to west over the Mediterranean) were made in proportionately less time than those in the opposite direction, in a ratio of 25 per cent. Thus we see that on the whole the east winds are stronger than those from the west.

SA LV. I am glad to know of this detail, which contributes not a little confirmation to the mobility of the earth. And though it may be said that all the water of the Mediterranean pours perpetually through the Straits of Gibraltar, having to disgorge into the ocean all the waters of so many rivers that empty into it, I do not believe that the current can be so strong that it alone could make such a remarkable difference. This is also evident from seeing that the water at Pharos runs back toward the east no less than it courses toward the west.

SAGR. I, who unlike Simplicio, have not been worrying about convincing anybody besides myself, am satisfied with what has been said regarding this first part. Therefore, Salviati, if you wish to proceed, I am ready to listen.

SALV. I am yours to command; but I should like to hear also how it looks to Simplicio, for from his judgment I can estimate how much I may expect from these arguments of mine in the Peripatetic schools, should they ever reach those ears.

SIMP. I do not want you to take my opinion asa basis for guessing at the judgments of others. As I have often said, I am among the tyros in this sort of study, and things which would occur to those who have penetrated into the profoundest depths of philosophy might never occur to me; for, as the saying goes, I have hardly greeted its doorkeeper. Yet to show some spark of fire, I shall say that as for the effects recounted by you, and this last one in particular, it seems possible to me to render quite sufficient reasons from the mobility of the heavens alone, without introducing any novelties beyond the mere converse of what you yourself have brought into the field.

It is admitted by the Peripatetic school that the element of fire and a large part of the air are carried around in the diurnal rotation from east to west by contact with the lunar sphere as their containing vessel. Now without deviating from your footprints, I should like us to establish the quantity of air participating in that motion as that part which ~ comes down about to the summits of the highest mountains, and would extend on down to the earth itself if the obstacle presented by these very mountains did not hinder it. Thus, just as you declared that the air surrounding the mountain ranges is carried around by the roughness of the moving earth, we say the converse-- that all the element of air is carried around by the motion of the heavens except that part which is lower than the mountain peaks, this being impeded by the roughness of the immovable earth. And where you would say that if such roughness were removed, this would also free the air from being caught, we may say that if this roughness were removed, all the air I would proceed in this movement. And since the surfaces of the open seas are smooth and level, the motion of the breeze which blows perpetually from the east continues there, and is more noticeable at places near the equator, within the tropics, where the motion of the heavens is most rapid.

And as this celestial movement is powerful enough to carry the free air with it, we may say quite reasonably that it contributes this same motion to the movable water. For this is fluid, and unattached to the earth's immobility. We may affirm this with the more confidence in view of your own admission that such a movement need be only very small with respect to its effective cause, which, going around the entire terrestrial globe in one natural day; passes over many thousands of miles per hour (especially near the equator), while currents in the open sea move but a very few miles per

hour. In this way our voyages toward the west would be much more convenient and rapid, being assisted not only by the

perpetual eastern breeze, but also by the course of the waters.

Perhaps from that same coursing of the water, tides also may arise; the water, striking against the variously situated shores, might even return straight back in the opposite direction, as experience shows us in the courses of rivers. For there the water, because of the irregularity of the banks, often meets some part which juts out or which makes a hollow from beneath, and it whirls around and is seen to return perceptibly. Hence it seems to me that the same effects from which you argue the mobility of the earth (and which mobility you offer as a cause for them) may be sufficiently explained if we hold the earth fixed and restore the mobility to the heavens.

SALV. It cannot be denied that your argument is ingenious and carries something of probability, but I say that this is a probability in appearance only and not in reality. There are two parts to your argument; in the first, you render a reason for the continual motion of the eastern breeze, and also for the motion of the water; in the second, you wish also to obtain a cause for the tides from the same source. The first part, as I have said, has some semblance of probability, though much less than we achieve from terrestrial motion. The second part is not only entirely improbable, but is absolutely impossible and false.

As to the first, in which you say that the hollow of the lunar sphere sweeps along with it the element of fire and all the air down to the summits of the highest mountains, I say first that there is doubt whether any element of fire exists. Even assuming that it does, it is extremely doubtful whether the lunar sphere exists; or indeed, whether any of the other "spheres" do. That is to say, it is questionable whether there actually are such bodies, solid and extremely vast, or whether beyond the air there does not rather extend a continuous expanse of a substance very much more tenuous and pure than our air, and whether the planets do not wander through this, as is now commencing to be held even by most of these same philosophers.

But however that may be, there is no reason for us to believe that fire, by simple contact with a surface which you yourself consider to be remarkably smooth and even, should in its entire extent be carried around in a motion foreign to its own inclination. This has been proved throughout II Saggiatore, and demonstrated by sensible experiments. Beyond this, there is the further improbability of such motions being transferred from most subtle fire to the air, which is much denser, and then from this to water.

But that a body of very rough and mountainous surface, by revolving, should conduct along with it the contiguous air which strikes against its prominences is not merely probable, but necessary; it may be seen from experience, although I believe that even without seeing it no one would cast doubt upon it.

As for the rest, assuming that the air and even the water were conducted by the motion of the heavens, such a motion would have nothing whatever to do with the tides. For since from one uniform cause only one single uniform effect can follow, there would have to be discovered in the waters a continual and uniform current from east to west, existing only in those oceans which, returning upon themselves, encircle the globe. In inland seas such as the Mediterranean, hemmed in as it is on the east, there could be no such motion. For if its waters were driven by the course of the heavens toward the west, it would have been dried up many centuries ago; besides which, our waters do not run only toward the west, but return back toward the east in regular periods. If indeed you should say, from the example of the rivers, that the course of the seas was originally from east to west only, but that the different situations of their shores might force some of the water to flow in reverse, then I shall grant you this, Simplicio; but you must take note that wherever the water is moved back for this reason, it perpetually returns again, while where it runs forward, it always keeps going in the same direction, as you may see from your example of the rivers. As to the tides, you must discover and bring forth reasons for making them run now one way and now the other at the same place--effects which, being contrary and irregular, you can never deduce from one uniform and constant cause. This, as well as overthrowing the idea of a motion being contributed to the sea by the diurnal movement of the heavens, also defeats those who would like to grant to the earth only the diurnal motion and who believe that with this alone they can give a reason for the tides. For since the effect is irregular, it is necessarily required that its causes shall be irregular and variable.

SIMP. I have nothing further to say; neither on my own account, because of my lack of inventiveness, nor on that of others, because of the novelty of the opinion. But I do indeed believe that if this were broadcast among the schools, there would be no lack of philosophers who would be able to cast doubt upon it.

SAGR. Then let us wait until that happens. In the meantime, if it is satisfactory with you, Salviati, let us proceed.

SALV. Everything that has been said up to this point pertains to the diurnal period of the tides, of which the primary and universal cause has first been proved, without which no effect whatever would take place. Next, passing on to the particular events to be observed in this diurnal period (which vary and are in a certain sense irregular), the secondary and concomitant causes upon which these depend remain to be dealt with.

Now two other periods occur, the monthly and the annual. These do not introduce new and different events beyond those already considered under the diurnal period, but they act upon the latter by making them greater or less at different parts of the lunar month and at different seasons of the solar year -- almost as though the moon and sun were taking part in the production of such effects. But that concept is completely repugnant to my mind; for seeing how this movement of the oceans is a local and sensible one, made in an immense bulk of water, I cannot bring myself to give credence to such causes as lights, warm temperatures, predominances of occult qualities, and similar idle imaginings. These are so far from being actual or possible causes of the tides that the very contrary is true. The tides are the cause of them; that is, make them occur to mentalities better equipped for loquacity and ostentation than for reflections upon and investigations into the most hidden works of nature. Rather than be reduced to offering those wise, clever, and modest words, "I do not know," they hasten to wag their tongues and even their pens in the wildest absurdities.

We see that the moon and the sun do not act upon small receptacles of water by means of light, motion, and great or moderate heat; rather, we see that to make water rise by heat, one must bring it almost to boiling. In short, we cannot artificially imitate the movement of the tides in any way except by movement of the vessel. Now should not these observations assure anyone that all the other things produced as a cause of this effect are vain fantasies, entirely foreign to the truth of the matter?

Thus I say that if it is true that one effect can have only one basic cause, and if between the cause and the effect there is a fixed and constant connection, then whenever a fixed and constant alteration is seen in the effect, there must be a fixed and constant variation in the cause. Now since the alterations which take place in the tides at different times of the year and of the month have their fixed and constant periods, it must be that regular changes occur simultaneously in the primary cause of the tides. Next, the alterations in the tides at the said times consist of nothing more than changes in their sizes; that is, in the rising and lowering of the water a greater or less amount, and its running with greater or less impetus. Hence it is necessary that whatever the primary cause of the tides is, it should increase or diminish its force at the specific times mentioned. But it has already been concluded that an irregularity and unevenness in the motion of the vessel containing the water is the primary cause of the tides; therefore this unevenness must become correspondingly still more irregular from time to time (that is, must increase or diminish).

Now we must remember that the unevenness (that is, the varying velocity of the vessels which are parts of the earth's surface) depends upon these vessels moving with a composite motion, the resultant of compounding the annual and the diurnal motions which belong to the entire terrestrial globe. Of these the diurnal whirling, with its alternate addition to and subtraction from the annual movement, is the thing that produces the unevenness of the compound motion. Thus the primary cause of the uneven motion of the vessels, and hence of that of the tides, consists in the additions and subtractions which the diurnal whirling makes with respect to the annual motion. And if these additions and subtractions were always made in the same proportion with respect to the annual motion, the cause of tides would indeed continue to exist, but only a cause for their being perpetually made in the same manner. Now we must find a reason for these same tides being made greater and less at different times; hence, if we wish to preserve the identity of the cause, there is a necessity of finding changes in these additions and subtractions, making them more and less potent at producing those effects which depend upon them. But I do not see how this can be done accept by making these additions and subtractions, now greater and now less, so that the acceleration and retardation of the composite motion shall be made now in a greater and now in a lesser ratio.

SAGR. I feel myself being gently led by the hand; and although I find no obstacles in the road, yet like the blind I do not see where my guide is leading me, nor have I any means of guessing where such a journey must end.

SALV. There is a vast difference between my slow philosophizing and your rapid insights; yet in this particular with which we are now dealing, I do not wonder that even the perspicacity of your mind is beclouded by the thick dark mists which hide the goal toward which we are traveling. All astonishment ceases when I remember how many hours, how many days, and how many more nights I spent on these reflections; and how often, despairing of ever understanding it, I tried to console myself by being convinced, like the unhappy Orlando, that could not be true which had been nevertheless brought before my very eyes by the testimony of so many trustworthy men. So you need not be surprised if for once, contrary to custom, you do not foresee the goal. And if you are nevertheless dismayed, then I believe that the outcome (which so far as I know is entirely unprecedented) will put an end to this puzzlement of yours.

SAGR. Well, thank God for not letting your despair lead you to the end that befell the miserable Orlando, or to that which is perhaps no less fictitiously related of Aristotle; for then everyone, myself included, would be deprived of the revelation of something as thoroughly hidden as it is sought after. Therefore I beg you to satiate my greed for it as quickly as you can.

SALV. I am at your service. We have arrived at an inquiry as to how the additions and subtractions of the terrestrial

whirling and the annual motion might be made now in greater and now in lesser ratios; for it is such a diversity, and nothing else, that may be assigned as a cause for the monthly and annual changes in the size of the tides. I shall next consider three ways in which this ratio of the additions and subtractions of the earth's rotation and the annual motion may be made greater and less.

First, this could be done by the velocity of the annual motion increasing and decreasing while the additions and subtractions made by the diurnal whirling remained constant in magnitude. For since the annual motion is about three times as fast as the diurnal motion, even taking the latter at the equator, then if we were to increase it further, the addition or subtraction of the diurnal motion would make less of an alteration. On the other hand if it were made slower, this same diurnal motion would alter it proportionately more. Thus to add or subtract four degrees of speed when dealing with something which moves with twenty degrees will alter its course less than if the same four degrees were added to or subtracted from something which moved with only ten degrees of speed.

The second way would be by making the additions and subtractions greater or smaller, retaining the annual motion at the same velocity. This is very easy to see, since it is obvious that a velocity of twenty degrees (for instance) will be altered more by the addition or subtraction of ten degrees than by the addition or subtraction of four.

The third manner would be a combination of these two, the annual motion diminishing and the diurnal additions and subtractions increasing.

As you see, it was easy to get this far; yet it was indeed a laborious task for me to discover how such effects could be accomplished in nature. Yet I finally found something that served me admirably. In a way it is almost unbelievable. I mean that it is astonishing and incredible to us, but not to Nature; for she performs with the utmost ease and simplicity things which are even infinitely puzzling to our minds, and what is very difficult for us to comprehend is quite easy for her to perform.

To continue, then: having demonstrated that the proportions between the additions and subtractions of the whirling on the one hand and the annual motion on the other may be made greater and less in two manners (I say two, because the third is a composite of the others), I add now that Nature does make use of both; and I add further that if she made use of but one of them, then one of the two periodic alterations of the tide would necessarily be removed. The monthly periodic changes would cease if there were no variation due to the annual motion, and if the additions and subtractions of the diurnal

rotation were kept always equal, then the annual periodic alterations would be missing.

SAGR. Then do the monthly alterations of the tides depend upon changes in the annual motion of the earth? And the annual alterations in the ebb and flow are derived from the additions and subtractions of the diurnal rotation? Now I am more confused than ever, and farther from any hope of being able to comprehend how this complication comes about, more intricate to my mind than the Gordian knot. I envy Simplicio, from whose silence I deduce that he understands everything and is free from the confusion that beclouds my imagination. **SIMP**. I really believe that you are confused, Sagredo, and I also think I know the cause of your confusion. In my opinion this originates from your understanding a part of what Salviati has set forth, and not understanding another part. And you are also correct about my not being confused at all, though not for the reason you suppose; that is, that I understand the whole thing. Quite the contrary; I understand nothing whatever of it, and confusion lies in the multiplicity of things -- not in nothing.

SAGR. You see, Salviati, how the checkrein that has been applied to Simplicio in the past sessions has gentled him, and changed him from a skittish colt into an ambling nag.

But please, without more delay, put an end to this suspense for both of us.

SALV. I shall do my best to overcome my obscure way of expressing myself, and the sharpness of your wits will fill up the dark places.

There are two events whose causes we must investigate; the first concerns the variation which occurs in the tides over a monthly period, and the other belongs to the annual period. We shall speak first of the monthly, and then deal with the annual; and we must first resolve the whole according to the axioms and hypotheses already established, without introducing any innovations either from astronomy or from the universe to help out the tides. We shall demonstrate that the causes for all the various events perceived in the tides reside in things previously recognized and accepted as unquestionably true. Thus I say that one true, natural, and even necessary thing is that a single movable body made to rotate by a single motive force will take a longer time to complete its circuit along a greater circle than along a lesser circle. This is a truth accepted by all, and in agreement with experiments, of which we may adduce a few.

In order to regulate the time in wheel clocks, especially large ones, the builders fit them with a certain stick which is free to swing horizontally. At its ends they hang leaden weights, and when the clock goes too slowly, they can render its vibrations more frequent merely by moving these weights somewhat toward the center of the stick. On the other hand, in order to retard the vibrations, it suffices to draw these same weights out toward the ends, since the oscillations are thus made more slowly and in consequence the hour intervals are prolonged. Here the motive force is constant --the counterpoise-- and the moving bodies are the same weights; but their vibrations are more frequent when they are closer to the center; that is, when they are moving along smaller circles.

Let equal weights be suspended from unequal cords, removed from the perpendicular, and set free. We shall see the weights on the shorter cords make their vibrations in shorter times, being things that move in lesser circles. Again, attach such a weight to a cord passed through a staple fastened to the ceiling, and hold the other end of the cord in your hand. Having started the hanging weight moving, pull the end of the cord which you have in your hand so that the weight rises while it is making its oscillations. You will see the frequency of its vibrations increase as it rises, since it is going continually along smaller circles.

And here I want you to notice two details which deserve ~ attention. One is that the vibrations of such a pendulum are made so rigorously according to definite times, that it is quite impossible to make them adopt other periods except by lengthening or shortening the cord. Of this you may readily make sure by experiment, tying a rock to a string and holding the end in your hand. No matter how you try, you can never succeed in making it go back and forth except in one definite time, unless you lengthen or shorten the string; you will see that it is absolutely impossible.

The other particular is truly remarkable; it is that the same pendulum makes its oscillations with the same frequency, or

very little different -- almost imperceptibly-- whether these are made through large arcs or very small ones along a given circumference. I mean that if we remove the pendulum from the perpendicular just one, two, or three degrees, or on the other hand seventy degrees or eighty degrees, or even up to a whole quadrant, it will make its vibrations when it is set free with the same frequency in either case; in the first, where it must move only through an arc of four or six degrees, and in the second where it must pass through an arc of one hundred sixty degrees or more. This is seen more plainly by suspending two equal weights from two threads of equal length, and then removing one just a small distance from the perpendicular and the other one a very long way. Both, when set at liberty, will go back and forth in the same times, one by small arcs and the other by very large ones.

From this follows the solution of a very beautiful problem, which is this: Given a quarter of a circle shall draw it here in a little diagram on the ground -- which shall be AB here, vertical to the horizon so that it extends in the plane touching at the point B; take an arc made of a very smooth and polished concave hoop bending along the curvature of the circumference ADB, so that a well-rounded and smooth ball can run freely in it (the rim of a sieve is well suited for this experiment). Now, say that wherever you place the ball, whether near to or far from the ultimate limit B -- placing it at the point C, or at D, or at E-- and let it go, it will arrive at the point B in equal times (or insensibly different), whether it leaves from C or D or E or from any other point you like; a truly remarkable phenomenon. Now add another, no less beautiful than the last. This is that along all chords drawn from the point B to points C, D, E, or any other point (taken not only in the quadrant BA, but in the whole circumference of the entire circle), the same movable body will descend in absolutely equal times. Thus, in the same time which it takes to descend along the whole diameter erected perpendicular to the point B, it will also descend along the chord BC, even when that subtends but a single degree or yet a smaller arc.

Figure 30

And one more marvel: The motions of bodies falling along the arcs of the quadrant AB are made in shorter times than those made along the chords of the same arcs, so that the fastest motion, made in the shortest time, by a movable body going from the point A to the point B will be along the circumference AOB and will not be that which is made along the straight line AB, although that is the shortest of all the lines which can be drawn between the points A and B. Also, take any point in that same arc (let it be, for instance, the point O), and draw two chords AO and OB; then the moving body leaving from the point A will get to Bin less time going along the two chords AO and OB than going along the single chord AB. The shortest time of all will be that of its fall along the arc AOB, and similar properties are to be understood as holding for all lesser arcs taken upward from the lowest limit B.

SAGR. Enough; no more; you are confusing me so with marvels, and are distracting my mind in so many directions, that I fear only a small part of it will remain free and clear for me to apply to the main subject we are dealing with -- which, I regret to say, is too obscure and difficult as it is. I beg you, as a favor to me, that when we have finished with the theory of the tides there shall be other days when you will again honor this house of mine and of yours, to discuss the many other problems that have been left dangling. Perhaps they will be no less interesting and elegant than these which we have been

problems that have been left dangling. Perhaps they will be no less interesting and elegant than these which we have been treating in the days just past, and which ought to be finished today.

SALV. I shall be at your disposal, though we shall have to have more than one or two sessions if, in addition to the questions reserved to be separately dealt with, we wish to add the many that pertain both to local motion and to the motions natural to projectiles -- subjects dealt with at length by our Lincean Academician.

Getting back to our original purpose, we were explaining that for things moved circularly by some motive force which is kept continually the same, the times of circulation are preestablished and determined, and impossible to lengthen or shorten. Having given examples of this and brought forth sensible experiments which we can perform, we may affirm the same to be true of our experience of the planetary movements in the heavens, for which the same rule is seen to hold: Those which move in the larger circles consume the longer times in passing through them. We have the most ready observations of this from the satellites of Jupiter, which make their revolutions in short times. So there is no question that

if, for example, the moon, continuing to be moved by the same motive force, were drawn little by little into smaller circles, it would acquire a tendency to shorten the times of its periods, in agreement with that pendulum which in the course of its vibrations had its cord shortened by us, reducing the radius of the circumference traversed. Now this example which I gave you concerning the moon actually takes place and is verified in fact. Let us remember that we had already concluded with Copernicus that it is not possible to separate the moon from the earth, about which it unquestionably moves in a month. Let us likewise remember that the terrestrial globe, always accompanied by the moon, goes along the circumference of its orbit about the sun in one year, in which time the moon revolves around the earth almost thirteen times. From this revolution it follows that the moon is sometimes close to the sun (that is, when it is between the sun and the earth), and sometimes more distant (when the earth lies between the moon and the sun). It is close, in a word, at the time of conjunction and new moon, it is distant at full moon and opposition, and its greatest distance differs from its closest approach by as much as the diameter of the lunar orbit.

Now if it is true that the force which moves the earth and the moon around the sun always retains the same strength, and if it is true that the same moving body moved by the same force but in unequal circles passes over similar arcs of smaller circles in shorter times, then it must necessarily be said that the moon when at its least distance from the sun (that is, at conjunction) passes through greater arcs of the earth's orbit than when it is at its greatest distance (that is, at opposition and full moon). And it is necessary also that the earth should share in this irregularity of the moon. For if we imagine a straight line from the center of the sun to the center of the terrestrial globe, including also the moon's orbit, this will be the radius of the orbit in which the earth would move uniformly if it were alone. But if we locate there also another body carried by the earth, putting this at one time between the earth and the sun and at another time beyond the earth at its greatest distance from the sun, then in this second case the common motion of both along the circumference of the earth's orbit would, because of the greater distance of the moon, have to be somewhat slower than in the other case when the moon is between the earth and the sun, at its lesser distance. So that what happens in this matter is just what happened to the rate of the clock, the moon representing to us that weight which is attached now farther from the center, in order to make the vibrations of the stick less frequent, and now closer, in order to speed them up.

From this it may be clear that the annual movement of the earth in its orbit along the ecliptic is not uniform, and that its irregularity derives from the moon and has its periods and restorations monthly. Now it has already been decided that the monthly and annual periodic alterations of the tides could derive from no other cause than from varying ratios between the annual motion and the additions to it and subtractions from it of the diurnal rotation; and that such alterations might be made in two ways; that is, by altering the annual motion and keeping fixed the magnitudes of the additions, or by changing the size of these and keeping the annual motion uniform. We have now detected the first of these two ways, based upon the unevenness of the annual motion; it depends upon the moon, and has its period monthly. Thus it is necessary that for this reason the tides should have a monthly period within which they become greater and smaller.

Now you see how the cause of the monthly period resides in the annual motion, and at the same time you see what the moon has to do with this affair, and how it plays a role without having anything to do with oceans or with waters.

SAGR. If a very high tower were shown to someone who had no knowledge of any kind of staircase, and he were asked whether he dared to scale such a supreme height, I believe he would surely say no, failing to understand that it could be done in any way except by flying. But being shown a stone no more than half a yard high and asked whether he thought he could climb up on it, he would answer yes, I am sure; nor would he deny that he could easily climb up not once, but ten, twenty, or a hundred times. Hence if he were shown the stairs by which one might just as easily arrive at the place he had adjudged impossible to reach, I believe he would laugh at himself and confess his lack of imagination.

You, Salviati, have guided me step by step so gently that r I am astonished to find I have arrived with so little effort at a height which I believed impossible to attain. It is certainly true that the staircase was so dark that I was not aware of my approach to or arrival at the summit, until I had come out into the bright open air and discovered a great sea and a broad

plain. And just as climbing step by r step is no trouble, so one by one your propositions appeared so clear to me, little or nothing new being added, that I thought little or nothing was being gained. So much the more is my wonder at the unexpected outcome of this argument, which has led me to a comprehension of things I believed inexplicable.

Just one difficulty remains from which I desire to be freed. If the movement of the earth around the zodiac in company with the moon is irregular, such an irregularity ought to have been observed and noticed by astronomers, but I do not know that this has occurred. Since you are better informed on these matters than I am, resolve this question for me and tell me what the facts are.

SALV. Your doubt is very reasonable, and in response to the objection I say that although astronomy has made great progress over the course of the centuries in investigating the arrangement and movements of the heavenly bodies, it has not thereby arrived at such a state that there are not I many things still remaining undecided, and perhaps still more which remain unknown. It is likely that the first observers of the sky recognized nothing but a general motion of all the stars -- the diurnal motion-- but I think it was not long before they discovered that the moon is inconstant about keeping company with the other stars. Years would have passed before they had distinguished all the planets, however. In particular, I believe that Saturn, on account of Its slowness, and Mercury, because of being rarely seen, were the last objects to be recognized as vagrant and wandering. Many more years probably passed before the stoppings and retrograde motions of the three outer planets were observed, and their approaches and retreats from the earth, which occasioned the need to introduce eccentrics and epicycles-- things unknown even to Aristotle, who makes no mention of them. How long did Mercury and Venus, with their remarkable phenomena, keep astronomers in suspended judgment about their true locations, to mention nothing else? Thus even the ordering of the world bodies and the integral structure of that part of the universe recognized by us was in doubt up to the time of Copernicus, who finally supplied the true arrangement and the true system according to which these parts are ordered, so that we are certain that Mercury, Venus, and the other planets revolve about the sun and that the moon revolves around the earth. But we cannot yet determine surely the law of revolution and the structure of the orbit of each planet (the study ordinarily called planetary theory); witness to this fact is Mars, which has caused modern astronomers so much distress. Numerous theories have also been applied to the moon itself since the time when Copernicus first greatly altered Ptolemy's theory.

Now to get down to our particular point; that is, to the apparent motions of the sun and moon. In the former there has been observed a certain great irregularity, as a result of which it passes the two semicircles of the ecliptic (divided by the equinoctial points) in very different times, consuming about nine days more in passing over one half than the other; a difference which is, as you see, very conspicuous. It has not yet been observed whether the sun preserves a regular motion in passing through very small arcs, as for example those of each sign of the zodiac, or whether it goes at a pace now somewhat faster and now slower, as would necessarily follow if the annual motion belongs only apparently to the sun and really to the earth in company of the moon. Perhaps this has not even been looked into.

As to the moon, its cycles have been investigated principally in the interest of eclipses, for which it suffices to have an exact knowledge of its motion around the earth. The progress of the moon through particular arcs of the zodiac has accordingly not been investigated in thoroughgoing detail. Therefore the fact that there is no obvious irregularity is insufficient to cast doubt upon the possibility that the earth and the moon are somewhat accelerated at new moon and retarded at full moon in traveling through the zodiac; that is, in going along the circumference of the earth's orbit. This comes about for two reasons; first, that the effect has not been looked for, and second, that it cannot be very large.

Nor is there any need for the irregularity to be very large in order to produce the effect that is seen in the alterations of the size of the tides. For not only the changes, but the tides themselves, are small with respect to the magnitude of the bodies in which they occur, though with respect to us and to our smallness they seem to be great things. Adding or deducting one degree of speed where there are naturally seven hundred or a thousand cannot be called a large change, either in what confers it or in what receives it; and the water of our sea, carried by the diurnal whirling, travels about seven hundred miles per hour. This is the motion common to it and to the earth, and therefore imperceptible to us. The motion which is made sensible to us in currents is not even one mile per hour (I am speaking of the open sea, and not of straits), and it is this that alters the great, natural primary motion.

Still, such a change is considerable with respect to us and to our ships. A vessel that can make, say, three miles per hour in quiet water under the power of its oars, will have its travel doubled by such a current favoring it instead of opposing it. This is a very notable difference in the motion of the boat, though it is quite small in the movement of the sea, which is

changed by only one seven-hundredth. I say the same of its rising and falling one, two, or three feet-- scarcely four or five feet even at the extremity of a basin two thousand or more miles long, where its depth is hundreds of feet. Such a change is much less than if, in one of the barges bringing sweet water to us, this water should rise in the prow by the thickness of a leaf at an arrest of the barge. From this I conclude that very small alterations with respect to the immense size and extreme speed of the oceans would be sufficient to make great changes in them in relation to the minuteness of ourselves and our phenomena.

SAGR. I am fully satisfied as to this part. It remains for you to explain to us how these additions and subtractions deriving from the diurnal whirling are increased or diminished, upon which alterations you hinted would depend the annual period of growth and diminution in the tides.

SALV. I shall use all my resources to make myself understood, but the difficulty of the phenomena themselves and the great abstractness of mind needed to understand them intimidate me.

The irregularity of the additions and subtractions which the diurnal rotation makes upon the annual motion depends upon the tilting of its axis to the plane of the earth's orbit, or ecliptic. By this tilting, the equator crosses the ecliptic and is inclined and oblique to it with the same slope as that of the axis. The magnitude of the additions amounts to as much as the entire diameter of the equator when the center of the earth is at the solstitial points, but outside of those it amounts to less and less according as the center approaches the equinoctial points, where such additions are least of all. This is the whole story, but it is wrapped in the obscurity which you perceive.

SAGR. Rather in that which I do not perceive, since so far I do not understand a thing.

SALV. That is just what I expected; nevertheless, we shall see whether the drawing of a little diagram will not shed some light on it. It would be better to represent this effect by means of solid bodies than by a mere picture; however, we may get some assistance from perspective and foreshortening. So let us show, as before, the circumference of the earth's orbit, the point A being supposed to be at one of the solstices and the diameter AP being the common section of the solstitial colure and the plane of the earth's orbit, or ecliptic. Suppose the center of the terrestrial globe to be located at this point A; its axis, CAB, tilted to the plane of the earth's orbit, falls in the plane of the said colure, which passes through the axes of both equator and ecliptic. To avoid confusion, we shall show only the equatorial circle, indicating this with the letters DGEF, whose common section with the plane of the earth's orbit will be the line DE, so that one half of the equator, marked DFE, will be below the plane of the earth's orbit, and the other half, DGE, will be above it.

Figure 31

It is now supposed that the revolution of the equator is in the order of the points D, G, E, F, and that the motion of the center is toward E. The center of the earth being at A, its axis CB (which is perpendicular to the equatorial diameter DE) falls as we said in the solstitial colure, the common section of this with the earth's orbit being the diameter PA; hence this line PA will be perpendicular to DE, because the colure is perpendicular to the earth's orbit. Therefore DE will be tangent to the earth's orbit at the point A, so that in this position the motion of the center along the arc AE, which amounts to one degree per day, would vary but little; it would even be as if it were along the tangent DAE. And since the diurnal rotation, carrying the point D through G to E, is increased over the motion of the center (which moves practically along this same line DE) by as much as the whole diameter DE, while on the other hand the other semicircle EFD is diminished by the same amount in its motion, the additions and subtractions at this point (that is, at the time of the solstice) will be measured by the entire diameter DE.

Next we shall see whether they are of the same magnitude at the times of the equinoxes. Transporting the center of the earth to the point I, one quadrant away from the point A, let us take the same equator GEFD, its common section DE with the ecliptic, and its axis CB at the same tilt. Now the tangent to the ecliptic at the point I will no longer be DE, but a different one, cutting this at right angles. This will be marked HIL, in the direction of which will be the motion of the center I, proceeding along the circumference of the earth's orbit. Now in this situation the additions and subtractions are not measured anymore by the diameter DE, as they were at first, f9rsince this diameter does not extend along the line of the annual motion HL, but rather cuts it at right angles, D and E add and subtract nothing.

The additions and subtractions must now be taken along that diameter which falls in the plane perpendicular to that of the earth's orbit and cutting it in the line HL let this be the diameter GF. The additive motion will then be made by the point G along the semicircle GEF, and the subtractive motion will be the balance, along the other semicircle FDG. Now this diameter being not in the same line as the annual motion, HL, but cutting it as is seen in the point I (with the point G being elevated above and F depressed below the plane of the earth's orbit), the additions and subtractions are not determined by its entire length. Rather, they must be that fraction of it taken between the parts of the line HL which are cut off between the perpendiculars drawn upon it from the points G and F, which would be two lines GS and FV: Hence the measure of the additions is the line SV, and this is less than GF or DE, which was the measure of the additions at the

solstice A.

According, then, to the placement of the center of the earth at any other point of the quadrant AI, we draw the tangent at such a point and drop perpendiculars upon it from the ends of the equatorial diameter determined by the plane through this tangent vertical to the plane of the ecliptic; and such apart of this tangent, which will be always less toward the equinoxes and greater toward the solstices, will give us the magnitudes of the additions and subtractions. Then as to how much the least additions differ from the greatest, this is easy to determine; between these there is the same variation as between the whole axis (or diameter) of the globe and that part of it which lies between the polar circles. This is less than the whole diameter by one-twelfth, approximately, assuming that the additions and subtractions are made at the equator; in other latitudes they are less in proportion as their diameters are diminished.

That is all I can tell you about the matter, and perhaps it is as much as can be comprehended within our knowledge--which, as is well known, can be only of such conclusions as are fixed and constant. Such are the three general periods of the tides, since these depend upon invariable causes which are unified and eternal. But with these primary and universal causes there are mixed others which, though secondary and particular, are capable of making great alterations; and these secondary causes are partly variable and not subject to observations (the changes due to winds, for example), and partly, though determinate and fixed, are not observed because of their complication. Such are the lengths of the sea basins, their various orientations in one direction or another, and the many and various depths of the waters. Who could possibly formulate a complete account of these except perhaps after very lengthy observations and reliable reports? Without this, what could serve as a sound basis for hypotheses and assumptions on the part of anyone who, from such a combination, wished to furnish adequate reasons for all the phenomena? And, I might add, for the anomalies and particular irregularities that can be perceived in the movements of the waters?

I am content to have noticed that incidental causes do exist in nature, and that they are capable of producing many alterations; I shall leave their minute observation to those who frequent the various oceans. I merely call to your attention,

in bringing this conversation of ours to a close, that the precise durations of the ebbing and flowing are changed not only by the lengths and depths of the basins, but I believe that noteworthy variations are also introduced by the juncture of various stretches of ocean which differ in size and in situation or, let us say, in orientation. Such a contrast occurs right here in the Adriatic Gulf, which is much smaller than the rest of the Mediterranean and is placed at such a different orientation that whereas the latter has its closed end in the eastern part at the shores of Syria, the former is closed at its western part. And since it is at the extremities that by far the greatest tides occur-- indeed, nowhere else are there very great risings and fallings-- it may very well be that the times of flood at Venice occur during the ebbings of the other sea. The Mediterranean, being much larger and extending more directly from west to east, in a certain sense dominates the Adriatic. Hence it would not be surprising if the effects that depend upon the primary causes were not verified in the Adriatic at the appointed times and corresponding to the proper periods, as well at least as they would be in the rest of the Mediterranean. But this matter would require long observations which I have not made in the past, nor shall I be able to make them in the future.

SAGR. It seems to me that you have done a great deal by opening the first portal to such lofty speculations. In your first general proposition, which seems to me to admit of no refutation, you have explained very persuasively why it would be impossible for the observed movements to take place in the ordinary course of nature if the basins containing the waters of the seas were standing still, and that on the other hand such alterations of the seas would necessarily follow if one assumed the movements attributed by Copernicus to the terrestrial globe for quite other reasons. If you had given us no more, this alone seems to me to excel by such a large margin the trivialities which others have put forth that just to think of those once more makes me ill. And I am much astonished that among men of sublime intellect, of whom there have been plenty, none have been struck by the incompatibility between the reciprocating motion of the contained waters and the immobility of the containing vessels, a contradiction which now seems so obvious to me.

SALV. What is more to be wondered at, once it had occurred to the minds of some to refer the cause of the tides to the motion of the earth (which showed unusual perspicacity on the part of these men), is that in seizing at this matter they should have caught onto nothing. But this was because they did not notice that a simple and uniform motion, such as the simple diurnal motion of the terrestrial globe for instance, does not suffice, and that an uneven motion is required, now accelerated and now retarded. For if the motion of the vessels were uniform, the contained waters would become habituated to it and would never make any mutations.

Likewise it is completely idle to say (as is attributed to one of the ancient mathematicians) that the tides are caused by the conflict arising between the motion of the earth and the motion of the lunar sphere, not only because it is neither obvious nor has it been explained how this must follow, but because its glaring falsity is revealed by the rotation of the earth being not contrary to the motion of the moon, but in the same direction. Thus everything that has been previously conjectured by others seems to me completely invalid. But among all the great men who have philosophized about this remarkable effect, I am more astonished at Kepler than at any other. Despite his open and acute mind, and though he has at his fingertips the motions attributed to the earth, he has nevertheless lent his ear and his assent to the moon's dominion over the waters, to occult properties, and to such puerilities.

SAGR. It is my guess that what has happened to these more reflective men is what is happening at present to me; namely, inability to understand the interrelation of the three periods, annual, monthly, and diurnal, and how their causes may seem to depend upon the sun and the moon without either of these having anything to do with the water itself. This matter, for a full understanding of which I need a longer and more concentrated application of my mind, is still obscure to me because of its novelty and its difficulty. But I do not despair of mastering it by going back over it by myself, in solitude and silence, and ruminating on what remains undigested in my mind.

In the conversations of these four days we have, then, strong evidences in favor of the Copernican system, among which three have been shown to be very convincing-- those taken from the stoppings and retrograde motions of the planets, and their approaches toward and recessions from the earth; second, from the revolution of the sun upon itself, and from what is to be observed in the sunspots; and third, from the ebbing and flowing of the ocean tides.

SALV. To these there may perhaps be added a fourth, and maybe even a fifth. The fourth, I mean, may come from the fixed stars, since by extremely accurate observations of these there may be discovered those minimal changes that Copernicus took to be imperceptible. And at present there is transpiring a fifth novelty from which the mobility of the earth might be argued. This is being revealed most perspicuously by the illustrious Caesar Marsili, of a most noble family at Bologna, and a Lincean Academician. He explains in a very learned manuscript that he has observed a continual change, though a very slow one, in the meridian line. I have recently seen this treatise, and it has much astonished me. I hope that he will make it available to all students of the marvels of nature.

SAGR. This is not the first time that I have heard mention of the subtle learning of this gentleman, who has shown

himself to be the zealous protector of all men of science and letters. If this or any other of his works is made public, we may be sure in advance that it will become famous.

SALV. Now, since it is time to put an end to our discourses, it remains for me to beg you that if later, in going over the things that I have brought out, you should meet with any difficulty or any question not completely resolved, you will excuse my deficiency because of the novelty of the concept and the limitations of my abilities; then because of the magnitude of the subject; and finally because I do not claim and have not claimed from others that assent which I myself do not give to this invention, which may very easily turn out to be a most foolish hallucination and a majestic paradox.

To you, Sagredo, though during my arguments you have shown yourself satisfied with some of my ideas and have approved them highly, I say that I take this to have arisen partly from their novelty rather than from their certainty, and even more from your courteous wish to afford me by your assent that pleasure which one naturally feels at the approbation and praise of what is one's own. And as f you have obligated me to you by your urbanity, so Simplicio has pleased me by his ingenuity. Indeed, I have become very fond of him for his constancy in sustaining so forcibly and so undauntedly the doctrines of his master. And I thank you, Sagredo, for your most courteous motivation, just as I ask pardon of Simplicio if I have offended him sometimes with my too heated and opinionated speech. Be sure that in this I have not been moved by any ulterior purpose, but only by that of giving you every opportunity to introduce lofty

thoughts, that I might be the better informed.

SIMP. You need not make any excuses; they are superfluous, and especially so to me, who, being accustomed to public debates, have heard disputants countless times not merely grow angry and get excited at each other, but even break out into insulting speech and sometimes come very close to blows.

As to the discourses we have held, and especially this last one concerning the reasons for the ebbing and flowing of the ocean, I am really not entirely convinced; but from such feeble ideas of the matter as I have formed, I admit that your thoughts seem to me more ingenious than many others I have heard. I do not therefore consider them true and conclusive; indeed, keeping always before my mind's eye a most solid doctrine that I once heard from a most eminent and learned person, and before which one must fall silent, I know that if asked whether God in His infinite power and wisdom could have conferred upon the watery element its observed reciprocating motion using some other means than moving its containing vessels, both of you would reply that He could have, and that He would have known how to do this in many ways which are unthinkable to our minds. From this I forthwith conclude that, this being so, it would be excessive boldness for anyone to limit and restrict the Divine power and wisdom to some particular fancy of his own.

SALV. An admirable and angelic doctrine, and well in accord with another one, also Divine, which, while it grants to us the right to argue about the constitution of the universe (perhaps in order that the working of the human mind shall not be curtailed or made lazy) adds that we cannot discover the work of His hands. Let us, then, exercise these activities permitted to us and ordained by God, that we may recognize and thereby so much the more admire His greatness, however much less fit we may find ourselves to penetrate the profound depths of His infinite wisdom.

SAGR. And let this be the final conclusion of our four days' arguments, after which if Salviati should desire to take some interval of rest, our continuing curiosity must grant that much to him. But this is on condition that when it is more convenient for him, he will remain and satisfy our desires-- mine in particular-- regarding the problems set aside and noted down by me to submit to him at one or two further sessions, in accordance with our agreement. Above all, I shall be waiting impatiently to hear the elements of our Academician's new science of natural and constrained local motions.

Meanwhile, according to our custom, let us go and enjoy an hour of refreshment in the gondola that awaits us.

END OF THE FOURTH AND FINAL DAY

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