Principles of Philosophy

René Descartes

[Brackets] enclose editorial explanations. Small ·dots· enclose material that has been added, but can be read as though it were part of the original text. Occasional •bullets, and also indenting of passages that are not quotations, are meant as aids to grasping the structure of a sentence or a thought. The basis from which this text was constructed was the translation by John Cottingham (Cambridge University Press), which is strongly recommended. Each four-point ellipsis . . . . indicates the omission of a short passage that seemed to be more trouble than it is worth. Longer omissions are reported between square brackets in normal-sized type.—Descartes wrote this work in Latin. A French translation appeared during his life-time, and he evidently saw and approved some of its departures from or additions to the Latin. A few of these will be incorporated, usually without sign-posting, in the present version.—When a section starts with a hook to something already said, it's a hook to •the thought at the end of the preceding section, *not* to •its own heading. In the definitive Adam and Tannery edition of Descartes's works, and presumably also in the first printing of the *Principles*, those items were not headings but marginal summaries.

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Contents

Part 3: The visible universe

1. We cannot over-estimate the vastness of the works of God.
The principles of material things that I have so far discovered have been derived not from the old prejudices of the senses but from the light of reason, so that their truth can't be doubted. Next question: Are these principles, unaided, sufficient for us to explain all natural phenomena, i.e. all the effects that we perceive through our senses? Let's start with the general structure of the entire visible world, because all the other phenomena depend on that one. In thinking about this, we must bear in mind two things. **(1)** One is the infinite power and goodness of God; we mustn't be afraid of over-estimating the vastness, beauty and perfection of his works. What we *should* be afraid of is appearing to *under*-estimate the magnificence of God's creative power by positing limits that we don't know for certain to exist.

2. Let's not be so presumptuous as to think we understand the ends God aimed at in creating the world.
The second thing we must bear in mind is **(2)** that our mental capacity isn't up to much, and we shouldn't have too high an opinion of ourselves. One way of doing this would be to assign limits to the world in the absence of knowledge based on reason or divine revelation—as if our powers of thought could stretch beyond what God has actually made! And it would be the height of presumption for us to suppose that we have the mental power needed to grasp the ends that God aimed at in creating the universe—let alone supposing that he did it all for our benefit!

3. The sense in which it can be said that all things were created for man.
In ethics it may be very right and proper to say that God made everything for our benefit, because this may stir us to thank him and burn with love for him all the more. And indeed there *is* a sort of truth in 'God made everything for our benefit', because we can make some use of all things, if only by thinking about them and being led by this to admire and wonder at God's marvellous works. But there isn't a chance that all things were *in fact* made for our benefit, if this means that's all they were for. . . . Obviously many things do or did exist that have never been seen or thought of by any man, and have never been of any use to anyone.

4. Empirical phenomena and their use in philosophy.
The principles that I have so far discovered are so vast and so fertile that their consequences vastly outnumber the entire observed contents of the visible world. There are so many of them, indeed, that we could never in a lifetime survey them completely, even in our thought. But I'll offer a brief account of the principal phenomena of nature whose causes we must now examine. I don't mean to use these phenomena as the basis for proving anything; I plan to deduce an account of effects from their causes, not of causes from their effects. My aim ·in starting with the phenomena, the effects,· is simply to get us to focus on some effects rather than others from among the countless effects that I think could be produced by the very same causes.

5. The ratio between the distances and sizes of the sun, earth and moon.
At first glance it seems that the earth is much larger than anything else in the world, and that the moon and sun are much larger than the other stars. But correcting his mistaken impression by infallible reasoning, we learn that the moon is separated from us by a distance of about thirty times the earth's diameter, and the sun by a distance six or

seven hundred times the earth's diameter. And by putting together •·what we know of· the distances from us the sun and the moon with •their apparent diameters, we learn that the moon is much smaller than the earth and the sun much larger.

6. How far the other planets are from the sun.

We also learn from observation aided by our reason that Mercury is more than two hundred earth-diameters from the sun, Venus more than four hundred, Mars nine hundred or a thousand, Jupiter more than three thousand, Saturn five or six thousand.

7. It is impossible to over-estimate how distant the fixed stars are.

As for the fixed stars, there's decisive empirical evidence that they aren't closer to the earth or the sun than Saturn is. But there's no such evidence that they aren't a truly enormous distance from us. Things I'll say later [section 40] about the movements of the heavens will imply that the fixed stars are so far from the earth that by comparison Saturn is a near neighbour.

8. Seen from the heavens, the earth would appear as a planet, smaller than Jupiter or Saturn.

9. The sun and the fixed stars shine by their own light.

The stars [here = 'the visible heavenly bodies of all kinds'] differ from one another not only in size but also in the fact that some shine by their own light while others only reflect light that comes to them from elsewhere. The sun first: if it were merely reflecting light that reached it from some other more brilliant body, we would be bound to see *that*; ·and we don't, so· it can't be doubted that the light with which the sun dazzles our eyes is its own . . . . Next the fixed stars: given how bright and glittering their rays are, although they are so far away from us and from the sun, it's easy to believe that they are like the sun in emitting their own light and that any one of them would appear as big and luminous as the sun if it were closer to us.

10. The light of the moon and the other planets is borrowed from the sun.

On the other hand, the Moon shines only on the side facing the sun, which tells us that it has no light of its own and merely reflects the rays it has received from the sun. The use of a telescope recently revealed the same thing to be true of Venus; and we can think the same about Mercury, Mars, Jupiter, and Saturn, because their light appears much weaker and less brilliant than that of the fixed stars, and because they are close enough to the sun to be illuminated by it.

11. There is no difference, with respect to light, between the earth and the planets.

12. The moon, when it is new, is illuminated by the earth.

13. The sun can be counted as one of the fixed stars, and the earth as one of the planets.

It's obvious that our earth, looked at from Jupiter, would appear smaller than Jupiter appears from here, but perhaps no less bright; and it would appear larger if viewed from some closer planet; but it couldn't be viewed at all from any of the fixed stars, because the distance would be too great. It follows from this that Earth is one of the planets, and the sun one of the fixed stars.

14. The fixed stars always keep the same distance from each other; the planets don't.

15. The observed motions of the planets can be explained by various hypotheses.

A man at sea in calm weather, looking at other vessels in the middle distance that seem to him to be changing their positions relative to one another, can't always tell whether a given apparent change comes from the motion of •that ship or •that other one or •the one he is on. Similarly, looking from our Earth at the paths the planets follow, we don't always learn enough—just by looking—to know whether a given apparent change of position comes from the movement of this or that planet or the movement of the Earth, and ·it is made even harder to sort them out by the fact that· these changes are very unequal and complicated. If we're to understand them, it will have to be with help from some explanatory theory about the planets, and it's for us to select the theory. Astronomers have come up with three different hypotheses—i.e. suppositions that they have offered not necessarily as true but as sufficient to explain all the phenomena.

16. Ptolemy's hypothesis doesn't account for the appearances.

The first of these hypotheses is Ptolemy's. I shan't discuss this: no-one accepts it these days because it conflicts with many recent observations, especially the observation that the lunar phenomenon of full-moon/half-moon/crescent-moon also occurs with Venus..

17. There's no difference between the hypotheses of Copernicus and Tycho, considered simply as hypotheses.

The second hypothesis is that of Copernicus and the third that of Tycho Brahe. These two, considered simply as hypotheses, account for the appearances in the same way and don't differ much, except that the Copernican version is a little simpler and clearer. Tycho would have had no reason to change it if he hadn't been trying to unfold •the actual truth of things and not a •mere hypothesis.

18. Tycho says that he attributes less motion to the earth than Copernicus does, but actually he attributes more.

Copernicus had no hesitation in attributing motion to the earth; Tycho 'corrected' him about this, regarding it as absurd from the point of view of physics and in conflict with the common opinion of mankind. But he didn't attend carefully enough to the true nature of motion—despite his insistence that the earth doesn't move at all he actually attributed to it more motion to it than Copernicus did!

19. My denial that the earth moves is more careful than Copernicus's and more correct than Tycho's.

The only difference between my position and those of Copernicus and Tycho is that I don't attribute any motion to the earth, thus keeping closer to the truth than Tycho while also being more careful than Copernicus. I'll put forward the hypothesis that seems to be the simplest of all both for understanding the phenomena and for investigating their natural causes. Regard this, however, simply as •an hypothesis and not as •the real truth. [In presenting his 'hypothesis', Descartes marks off four parts of it as 'First' section 20, 'Second' sections 21–3, 'Third' sections 24–5, and 'Fourth' sections 26 to (probably) 29.]

20. The fixed stars must be supposed to be much, much further off from us than Saturn is.

Astronomers all agree that the fixed stars are further from us than Saturn is, but I propose that we go further than that. We don't know for sure how far away the fixed stars are, but no story about them could possibly put them so far away as to be in conflict with the phenomena; so let's not be content with merely putting them 'somewhere beyond Saturn', instead supposing them to be as far beyond Saturn as will serve our purpose. It doesn't matter if the distance we propose seems incredible by the standards of earthly distances, because the minimum distance that everyone agrees on—namely 'further off than Saturn'—is already incredible by earthly standards! And when we bear in mind the omnipotence of God who created the fixed stars, •the greatest conceivable distance is at least as credible as •any smaller one. And I'll show later that we have to suppose an enormous distance between the fixed stars and the sphere of Saturn if we are to explain satisfactorily the empirical facts about the planets and the comets.

21. The sun, like a flame, is composed of extremely mobile matter, but that doesn't mean that it moves from place to place.

Because the sun gives off its own light, like •fire and like •the fixed stars, let us suppose that it resembles •fire in its motion and the fixed stars in its •situation. ·That means that there is motion in the sun—a great deal of motion—because· there's nothing more mobile than fire to be seen on the earth (as witness the fact that the bodies fire touches, if they aren't extremely hard, gradually disintegrate and allow their constituent particles to get caught up in the motions of the fire). But this motion consists only in each of its parts moving in relation to the others; the fire as a whole doesn't move from one place to another unless it is carried by some body to which it is adhering. So we can reasonably think that the sun is composed of very fluid and mobile matter which eats into the surrounding parts of the heaven, while judging that it resembles the fixed stars in not moving from place to place in the heaven. [By 'heaven' Descartes means a large spherical mass of rotating fluid material, having a fixed star at its centre. So there are as many heavens as there are fixed stars. This note comes from the translation of the complete work by V. R. and R. P. Miller (Reidel, 1983).]

22. The sun differs from a flame in not requiring fuel in the same way.

'Your comparison of the sun with fire doesn't hold good, because fire that we see here on earth always needs fuel, and the sun seems not to do so.' Not so. According to the laws of nature, *anything* once it has been formed continues to exist unless destroyed by some external cause—and that goes for fire as much as for everything else. Then why does fire on earth need fuel? Strictly speaking, it *doesn't*! That is, it doesn't need fuel in order to stay exactly as it is. But ·it can't unaided stay exactly as it is, because· its fluidity and mobility lead to its being constantly dissipated by the matter surrounding it; and the need for fuel comes from the need to create a new fire as the old one is extinguished. But the sun is not dissipated in that way by the heavenly matter surrounding it, so we have no reason to think that *it* needs to be fed like ·earthly· fire. . . .

23. The fixed stars don't all turn on the same sphere. Each is surrounded by a vast space that isn't occupied by any other star.

Some astronomers have thought that all the fixed stars are situated on the surface of a single sphere, but that can't be right if the sun is one of the fixed stars (or anyway is like the fixed stars in the facts about how it is situated). ·Why not? Because it's empirically obvious that the sun is much nearer to us than the fixed stars are, and therefore doesn't share a sphere-surface with them·. The real situation is that the sun is surrounded by a vast space with no fixed stars in it, ·and the same must be true of each fixed star·. So each fixed star must be very distant from all the others, and the fixed stars must vary widely in how far they are from the sun and from us. . . .

24. The heavens are fluid.

It's not just the sun and the fixed stars that are fluid; so also is every heaven. This is generally accepted by astronomers these days, because they can see that otherwise it's almost impossible to explain the observed facts about the planets.

25. The heavens carry along with them all the bodies that they contain.

Many of the astronomers regard a heaven as an entirely empty space—something that not only offers no resistance to the motion of other bodies but also lacks the force to carry other bodies along with it as it moves. [Descartes's wording of that seems to suggest that 'x is an empty space' goes further than 'x is fluid'—suggesting that emptiness is fluidity redoubled in spades, so to speak.] They are wrong about this, I think, because such a void cannot exist in nature. ·And a heaven's being fluid doesn't imply that it is a vacuum. The reason why **(1)** fluids offer so little resistance to the motions of other bodies is not that they contain so little matter but rather that **(2)** their constituent particles are in motion relative to one another; for an account of how **(1)** follows from **(2)** see section 2:56·. If this motion takes all the particles in some one direction, the fluid will have to—by the force of this motion—carry with it all the bodies that are immersed in it unless some external cause holds them back, even bodies that are very hard and are initially motionless. This follows obviously from what I said in 2:61.

26. The earth is at rest in its own heaven which nevertheless carries it along.

We see that the earth isn't supported by columns or held up by cables, but is completely immersed in a very fluid heaven. Let us assume that the earth is at rest, having no innate tendency to motion (because we don't see any such propensity). But let's not think that this prevents the earth from being carried along by the current of that heaven, following the motion of the heaven without itself *moving*. Compare this with an unanchored ship that isn't driven by the wind or by oars, floating motionlessly in the middle of the ocean, though it may be imperceptibly carried along by the ebb and flow of this great mass of water.

27. The same view should be taken of all the planets.

And just as the other planets resemble the earth in being opaque and reflecting the rays of the sun, there's reason to believe that they also resemble it in remaining at rest, each in its own part of the heaven, and that the observed variations in their positions results solely from the motion of the matter of the heaven in which they are immersed.

28. Strictly speaking the earth doesn't move, nor do the planets, though they're all carried along by the heaven.

Bear in mind what I said in section 2:25 about the nature of motion, namely: If we use the term 'motion' in the strict sense and in accordance with the truth of things, then motion is simply the transfer of one body away

•from contact with one set of bodies to contact with another set,

where the former set are regarded as being at rest. But quite often in accordance with ordinary usage people will label as 'motion' any event in which a body travels

•from one place to another place;

this being the sense in which a thing can be said to move and not to move at the same time, because of different choices we can make of what is to count as its 'place'. In the strict sense, the earth is not moving, nor are the other planets; because they are not transferred from the vicinity of those parts of the heaven with which they are in immediate contact, in so far as these parts are considered as being at rest. [Descartes's explanation of this is too compact to be easily followed. The basic point is his thesis that the earth and other planets revolve around the sun in what he calls 'a heaven', a closed-loop river of 'celestial material'; so that the earth (for example), although it moves around the sun in the ordinary language sense of 'moves', *doesn't* move at all in Descartes's 'strict' and 'in-conformity-with-the-truth' sense of 'move', because it doesn't move away from its immediate neighbours but is herded along by them all the way. There's a slight complication because the tiny particles of the celestial fluid are constantly moving relative to one another, so that there *are* constant changes in exactly which bits of matter are in direct contact with the earth. But this doesn't conflict with the thesis that the earth doesn't strictly move, because] the motion of the particles should be attributed solely to the particles, not to the earth. In the same way, the partial transfers of water and air that occur on the surface of the earth are normally attributed not to the earth itself but to the parts of water and air which are transferred.

29. If 'motion' is taken in its loose ·ordinary-language· sense, it's correct to say that the planets other than the earth move, but it's still not correct to say that the earth moves.

If we use 'motion' in the ordinary way, then we should say that all the other planets and even the sun and fixed stars *move*; but it doesn't sound right to say that *the earth* moves, even when we are using 'move' in its ordinary informal sense. Here is why. The common practice is to determine the position of the stars from certain sites on the earth that are regarded as immobile: the stars are thought to move when they pass these fixed spots. This is convenient for practical purposes, and so it is reasonable. Indeed all of us since infancy have thought of the earth not as a globe but as a flat surface, so that 'up' and 'down' are everywhere the same, and the four directions—east, west, south and north—are the same for any point on the surface; and we have all used these directions for specifying the location of any other body. But what of a philosopher [here = 'scientist'] who realizes that the earth is a sphere immersed in a fluid and mobile heaven, and that the sun and the fixed stars always keep the same positions relative to each other? If he takes these bodies as immobile for the purpose of determining the earth's location, and thus says that the earth moves, his way of talking is quite unreasonable. On the one hand, 'location' in •the philosophical sense is settled in terms of bodies that are right next to the body that is said to move—not in terms of very remote bodies like the stars. And on the other hand, if we follow •ordinary usage, we have no reason to think that it's the stars that are at rest rather than the earth. Consider this possibility:

> **P**: There are other bodies even further away than the stars ·that we can see·, bodies from which •the stars are receding and with reference to which •they can be said (ordinary usage) to *move* and •the earth can be said (ordinary usage) to be at rest.

If **P** is true, then it isn't true (ordinary usage) that the earth moves. And to reject **P** is irrational. Our minds are so built that they don't recognize any limits in the universe; so anyone who thinks about God's immensity and the weakness of our senses will conclude that it is much more reasonable to suspect that ·**P** may be true, i.e. that· there may be other bodies beyond all the visible 'fixed' stars, and that with reference to *those* bodies the earth can be said to be at rest while all the ·visible· stars may be said to be in motion. This is surely more reasonable than to suppose that there can't possibly be any such bodies ·and thus that **P** *can't* be true·. [The French version added:] Someone who in this way thinks that the earth moves must be rejecting **P** on the grounds that the creator's power is not great enough. And if later on ·in this work· I seem to attribute motion to the earth, remember that this is an improper way of speaking—like saying of someone asleep on a ferry that he is 'moving' from Calais to Dover.

30. All the planets are carried round the sun by the heaven.

Let's stop worrying about the earth's motion and suppose that the whole of the celestial matter—·the heaven·—in which the planets are located turns continuously like a vortex with the sun at its centre. Let us suppose further that the parts of the vortex nearer to the sun move faster than the parts further out from the sun, and that all the planets (earth included) always stay surrounded by the same portions of celestial matter. This single supposition lets us smoothly explain all the observed movements of the planets without bringing in any supplementary apparatus. At some places along a river the water twists around on itself and forms a whirlpool with bits of straw floating in it, ·and four features of this can help us to understand planetary motion·. **(1)** We see the straws carried around with the whirlpool. **(2)** Sometimes we see a straw also spinning around its own centre. **(3)** The straws nearer the centre of the whirlpool complete a revolution more quickly ·than the ones further out·. **(4)** Although such a straw always has a circular motion, it almost never follows a perfect circle—there are usually some deviations from that. We can easily imagine all this happening in the same way with the planets, so that this single account explains all the planetary movements that we observe.

31. How the individual planets are carried along.

32. The movement of sun spots.

33. How the earth rotates about its own centre, and the moon revolves around the earth.

34. The motions of the heavens are not perfectly circular.

35. The planets' deviations from the plane of the ecliptic.

36. Their longitudinal motion around the sun.

37. This hypothesis makes it easy to understand all the observations ·of the planets·.

38. According to Tycho's hypothesis the earth should be said to move about its own centre.

39. It should also be said to move annually around the sun.

40. The earth's movement ·around the sun· doesn't affect the apparent positions of the fixed stars because they are so far away.

You may want to object: 'Given that the sun always keeps the same position in relation to the fixed stars, the earth's great year-long circle around the sun must bring it nearer to any given fixed star at some times than it is at others; but this isn't confirmed by any observations that have been made.' The answer is that the fixed stars are too far away from the earth for these changes of distance to be observable ·by any means that we have·. The distance that I suppose there to be between the earth and any fixed star is so immense that the whole circle of the earth's path around the Sun should be counted as a mere point in comparison to it. Some people may find this incredible—I mean those whose minds aren't accustomed to contemplating God's mighty works, and who see the earth as the most important part of the universe because •it's where men live and (they think) •everything was created for men. But astronomers won't find it so strange, because they already know that the earth is like a mere point in comparison with the heaven.

41. The supposition that the fixed stars are very distant is also required to explain the motion of comets, which are now agreed to be celestial bodies.

42. All the things we see here on earth are among the phenomena ·to be explained·, but we needn't consider them all from the outset.

The phenomena ·to be covered· include not only these rather general ones but also many particular matters concerning the sun, the planets, the comets and the fixed stars, and also concerning the earth—*all* the facts about what we see happen on its surface. If we're to discover the true nature of this visible world [here = 'universe'], it's not enough to find causes that explain what we see far off in the heavens; *those same causes* must also explain everything that we see right here on earth. We can discover the causes of more general things without first looking into all these terrestrial phenomena; but we'll know that we are right about those causes when we observe that serve to explain not only •the effects that we were initially trying to explain but •all these other phenomena that we hadn't even been thinking about.

43. If there's a causal story from which all the phenomena can be clearly deduced, then it's virtually impossible for it not to be true.

If •we use only principles that we see to be utterly evident, and •all our subsequent deductions follow by mathematical reasoning, and •what the deductions lead to are in precise agreement with all natural phenomena, wouldn't we be doing God an injustice if we suspected that the causal explanations reached in this way were false? It would imply that God had endowed us with such an imperfect nature that even the proper use of our powers of reasoning allowed us to go wrong.

44. Still, I want the causes that I shall set out here to be regarded simply as hypotheses.

When philosophizing about such important matters, however, it would be downright arrogant to claim that I have discovered the exact truth where others have failed; so I choose not to make such a claim, and to offer everything that I'm going to write simply as a hypothesis. And if you think the hypothesis is false, I'll still think that I have done something pretty worthwhile if everything deduced from it agrees with our observations; because in that case the hypothesis will be as useful as if it were true—useful, that is, in enabling us to manipulate natural causes so as to get the effects we want.

45. I shall even make some assumptions that are certainly false.

Indeed, to improve my explanation for things found in nature I shall take my investigation of their causes back to a time before (I think) those causes actually came into existence, ·which means that my explanatory scheme will include some things that are downright false·. It is beyond question that the world was created right from the start with all the perfection it now has: the sun and earth and moon and stars existed in the beginning, the earth contained not just seeds but full-grown plants, and Adam and Eve weren't born as babies but created as fully grown people. That's what the Christian faith teaches; and our natural reason also convinces us that it is true, because we can't think that God in his infinite power ever created anything that wasn't entirely perfect [partly meaning 'complete', 'finished'] of its kind. Still, if we want to understand the *natures* of plants or of men, it's much better to consider •how they might gradually grow from seeds than to consider •how they were created by God ·as going concerns· at the start of the world. In this spirit perhaps we can think up some very simple and easily grasped principles that can function as the seeds (so to speak) from which the stars, the earth and indeed everything we observe in this visible world demonstrably could have grown. We know for sure that they *didn't* arise in this way, but we'll be able to explain their nature much better in this way than if we merely described them as they now are or as we believe them to have been created. Well, I believe that I *have* found such principles, and I'll give a brief account of them here.

46. The assumptions that I am making here in order to explain all phenomena.

I have established that all the bodies in the universe are composed of a single ·mass of· matter that is •*divisible* into indefinitely many parts, and is in fact •*divided* into very many parts that move in different directions and have a sort of circular motion; and that the same quantity of motion is always preserved in the universe. But unaided reason won't tell us how big these pieces of matter are, how fast they move, or what kinds of looped path they follow. [See the note in 2:33.] There are countless configurations that God might have chosen, and experience will have to tell us which ones he actually chose. So we're free to make any assumption we like about this, provided that its consequences agree with our experience. Allow me then to suppose that God originally divided the matter of which the visible world is composed into particles of about the same size, a *moderate* size, between the biggest and smallest that now make up the heavens and stars. I'll also suppose that their total amount of motion was the same as what is now found in the universe; and that their motions were of two kinds, of equal force. **(1)** They moved individually and separately about their own centres, so as to form a fluid body such as we take the heavens to be. **(2)** They moved together in groups around certain other equidistant points corresponding to the present centres of the fixed stars, and around other more numerous points equalling the number of the planets, ... so as to make up as many different vortices as there are now heavenly bodies in the universe.

47. These suppositions are false, but that doesn't prevent the consequences deduced from them being true and certain.

These few assumptions, I think, are all we need as causes or sources from which all the effects observed in our universe would arise in accordance with the laws of nature that I presented in 2:37–40. And I don't think anyone could come up with any alternative sources for explaining the real world that are simpler, easier to understand, or more probable. It may be possible to start from primeval chaos and deduce from that, in accordance with the laws of nature, the precise organization now to be found in things; and I once undertook to do this. But •confusion seems less in accordance with the creator's supreme perfection than •proportion or order; and it is also harder for us to think about clearly. And if we are going to work ·not with chaos but· with proportion or order, the simplest and easiest to grasp is complete equality in every respect. That's why I am supposing at this point that all the particles of matter were initially equal in size and speed, and am allowing no inequality in the universe apart from the one that exists in the position of the fixed stars [presumably meaning 'the irregularity of the distribution of fixed stars through space'], which can't possibly be denied because any who looks at the night sky sees it staring him in the face. In fact it doesn't make much difference what initial suppositions are made, because:

> •all subsequent change must occur in accordance with the laws of nature; and •as long as those laws are followed, the same effects could be derived (perhaps more laboriously) from almost any supposition about the initial conditions.

That's because by the operation of these laws matter must successively assume all the forms of which it is capable; and if we consider these forms in order we'll eventually arrive at the form that characterizes the universe in its present state. So we have no reason to fear that in these matters we'll be led into error by starting with a false supposition.

48. How the particles of celestial matter become spherical.

To make a start on showing how the laws of nature work in the context of the hypothetical system I have proposed, I call your attention to this: The particles of matter of which the world is composed couldn't *all* have started out as spherical [*sphæricas*], because I have shown that our universe has no •empty spaces, and you can't completely •fill a space with spheres. But whatever shape these particles had at the outset, they *had to* become round [*rotundas*] in the course of time because of their various closed-loop [*circulares*] motions. ·Would the particles really have had enough force for all that rounding, all that knocking off of corners? Yes indeed!· At the outset the particles had enough force to separate them from one another; that's more than enough force for them subsequently to knock the corners off one another; and the total force present in the world doesn't lessen over the course of time. In this context, anything that protrudes beyond the spherical figure is called a 'corner', so that it obviously follows from this:

> •the particles eventually grind down all one another's corners

that this is true:

> •the particles eventually become spherical.

49. The spaces between these spherical particles must be filled by other more finely divided matter.

Because there can't be any empty space in the universe, and because spherical particles can't unite so closely as to leave no spaces around them, these spaces must be filled by scrapings of matter that are extremely tiny and able to change their shapes at any moment so as to fit into the spaces they enter. ·The scheme of things I am putting forward easily provides for these needed tiny and malleable chips of matter, because this is the story it tells·: Matter that is knocked off the corners of the particles of matter that are becoming spherical is gradually ground down to form particles that are so tiny and so fast-moving that through the sheer force of their motion they •come to have no exact shape and size and •can easily fill spaces that other parts of matter can't enter.

50. The particles of this more finely divided matter can be very easily divided.

The smaller these scrapings of other particles are, the more easily they can be •moved and •made even smaller still. That's because the smaller they are the more surface area they have in proportion to their bulk. ·For example,

> •a cube of 8cm^3 has a surface area of 24cm^2;

(a cube with that volume measures 2cm along each side, so each side measures 4cm^2, and there are six sides); whereas

> •a cube of 1cm^3 has a surface area of 6cm^2;

which means that reducing the bulk to one-*eighth* reduces the surface area only to one *quarter*·. The upshot of this is that as a particle is ground down to a smaller and smaller size,

> •the area across which it can confront other bodies that can grind it down further

is not reduced as much as

> •the bulk that enables it to resist such grinding-down.

51. And they move very quickly.

When a little bit x is knocked off a larger particle y that is on the way to becoming spherical, x gets all its motion from y and yet moves much faster than y and its like do. Why? Because y and its like travel by straight and open paths, pushing x and *its* like along zig-zag paths that are narrower. What does that have to do with *speed*? Well, think about how by closing a bellows •slowly we can force the air out of it •rapidly, because the opening the air has to go through is so small.—You'll recall that in 2:33–5 I showed that for matter to move in closed loops at varying speeds, without allowing either rarefaction or empty space, there must be matter that moves extremely quickly and is divided into indefinitely many parts. I can't imagine how this theoretical need could be better met than it is by what I have said in these two sections about the size, speed and malleability of the 'scrapings'.

52. There are three elements of this visible world.

The two most basic elements of this visible universe are the following. **(1)** The first element is composed of matter that is so violently agitated that when it meets other bodies it splits into particles of indefinite smallness, adapting itself to the shapes needed for it to fill all the gaps between the larger particles. **(2)** The second element is composed of matter divided into spherical particles which are still much too small to be separately visible but have definite fixed sizes, though they can be divided into other much smaller particles. **(3)** The third element, which I'll expound soon, consists of particles that either •are much bulkier or •have shapes less suited for motion. I am going to show that all the bodies in this visible universe are composed of these three elements—

- •the sun and fixed stars are composed of the first element,
- •the heavens are composed of the second, and
- •the earth and planets and comets are composed of the third.

How will I show that? Well, the sun and the fixed stars **(1)** emit light, the heavens **(2)** transmit light, and the earth and the planets and comets **(3)** reflect light; and I'm going to argue that these three relations to light are explained by the threefold difference in the material components of the sun, the heavens etc.

53. Three heavens can also be distinguished in it.

54. How the sun and fixed stars were formed.

55. What light is.

It is a law of nature that any body moving in a circle will, if left to itself, move away from the centre of that circle—·see 2:39·. I shall now explain as carefully as I can the force by which the globules of the second element. . . .try to move away from their centres of motion; because that is the whole story about the nature of light (as I shall show later), and many other matters also depend on knowledge of this point. [Light is discussed in sections 64 and 77–81, but the 'later' passage Descartes is referring to is probably 4:28.]

56. How to understand an inanimate thing's 'trying' to move.

When I say that the globules of the second element 'try' to move away from the centres around which they revolve, don't take me to mean that they are trying on the basis of some thought that they have! All I mean is that their location and their state of arousal [*incitatos*] are such that they *will* travel in that direction unless some cause prevents them from doing so.

57. How one body can be said to try to move in different directions at the same time.

It often happens that a single body is subjected to many different causes at once, and these causes may interfere with one anothers' effects. So we can tell different stories about the direction a given body is tending or trying to move in, depending on which of the causes we are considering. Consider a stone that is being swung around a circular path in a sling. At the instant when it is at the bottom of the circle, how does it tend or try to move?

> **(1)** The stone tends or tries to continue upwards along the circle;

that's the right answer if all the relevant causes are taken into account, because that is the path that the stone does in fact follow.

> **(2)** The stone tends or tries to shoot out along a tangent to the circle, parallel to the ground;

that's the right answer if we focus just on the power of moving that the stone itself has, because that's the line that the stone *would* travel if it were released from the sling at that instant. The sling prevents that from happening, but it doesn't eliminate the 'trying'.

> **(3)** The stone tends or tries to fall straight down to the ground;

that's the right answer if we focus on the part of the stone's total power of moving that is resisted by the sling, distinguishing this from the remaining part of its power that produces the actual result.

58. How bodies moving in a circle try to move away from their centre of motion.

59. The extent of the force of this trying.

60. This trying is found in celestial matter.

61. This is the cause of the sun and the fixed stars being round.

62. It is also the reason why celestial matter tries to move away from all the points of the circumference of each star or of the sun.

63. The globules of celestial matter don't hinder each other in this trying.

64. This trying explains all the properties of light. And as a result of it, light could be seen to emanate from the stars, despite the lack of any light-producing force in the stars themselves.

65. The poles of each celestial vortex touch the parts of other vortices which are remote from their poles.

66. There must be some deflection in the motion of the vortices so that they can move in harmony.

67. Two vortices cannot touch at their poles.

68. The vortices are of unequal size.

69. The matter of the first element flows from the poles of each vortex towards its centre, and from the centre towards the other parts.

70. The same thing cannot be supposed to occur with the matter of the second element.

71. The reason for this difference.

72. How the matter of which the sun is made moves.

73. There are various inequalities in the position of the solar body.

74. There are also various inequalities in the movements of its matter.

75. These inequalities don't prevent the shape of the sun from being round.

76. The motion of the first element as it travels between the globules of the second element.

77. How the light of the sun is diffused not only towards the ecliptic but also towards the poles.

78. How it is diffused towards the ecliptic.

79. The motion of one small body readily produces motion in other bodies which are so exceedingly remote from it.

80. How the light of the sun moves towards the poles.

81. Whether the strength of the light at the ecliptic is equal to that at the poles.

82. The globules of the second element that are near the sun are smaller and faster-moving than more distant ones. . . .

83. Why very remote globules move faster than ones that are somewhat nearer.

84. Why the globules closest to the sun move faster than ones that are slightly further away.

85. Why the globules nearest to the sun are smaller than ones that are further away.

86. The globules of the second element move in various different ways at the same time; and as a result they become completely spherical.

87. There are various degrees of speed in the tiny particles of the first element.

Having gone some distance towards explaining the nature of the first two elements, we should turn to the third, but I can't do that without first making some more points about the first element. [In fact, Descartes doesn't mention the third element until section 117, where he mentions in passing that sunspots belong to it. The third-element concept starts getting real work to do only in section 121.] The particles making up the matter of the first element don't all move at the same speed; it can often happen that a very small quantity of this matter has particles moving at countless different speeds. It's extremely easy to demonstrate this, on the basis of **(1)** the account I have given of what brought the first element into existence and of **(2)** the ongoing need for it to perform a certain function. [Descartes goes on to remind us of **(1)** his story about second-element particles gradually becoming spherical by having their corners knocked off, with the spaces between them being occupied by the chips and scrapings of the knocking-off procedure. And he adds that **(2)** there's an ongoing need for the tiny bits of (first element) matter to perform the space-filling role. He goes on from there to make his main point in this section: The space-filling job means that there is no limit to how small some first-element particles are, while the story about their origin gives no reason for thinking they are *all* indefinitely small. So they vary in size; so they vary in speed.]

88. The slowest tiny particles easily transfer what speed they have to other particles, and stick to one another.

So some of the first-element scrapings are less finely divided than the rest and less rapidly agitated. And since we are supposing these scrapings to have been knocked off the corners of second-element particles . . . ., they *have to* have extremely angular shapes, ill-adapted to movement. As a result, they easily stick to one another and transfer much of their agitation to other scrapings—the ones that are the tiniest and most rapidly agitated. . . .

89. Such clusters of tiny particles are chiefly found in the matter of the first element which is carried from the poles of the vortices to their centres.

Such slow-moving clustering particles are mainly found in first-element matter that is moved in straight lines from the poles of each heaven toward its centre. That's because straight-line movement requires less speed than the more crooked and diverse movements that occur in other places. Thus, when these particles are in such 'other places' they are usually expelled into the path of this straight movement, where they cluster together to form certain bodies—·larger than their constituent particles, of course, but still *small*·—the shape of which I wish to consider very carefully.

90. The shape of these 'striated particles', as I'll now label them.

They must be triangular in cross-section, of course, because they often pass through the narrow triangular spaces which that created when three second-element globules touch. It's not easy to determine the length of any particle, because that seems to depend solely on how much matter came together to form it; but all we need just now is to determine (not their •lengths but) their •shapes, which we must conceive as small fluted cylinders with three grooves or channels which are twisted like the shell of a snail. This enables them to corkscrew their way through the little triangular spaces that always occur when three globes of the second element come together—curved-line triangles, ·of course, not straight-line ones·. [Descartes continues with a difficult account of why these particles need to be corkscrewed as they are. His use of this in the next section suggests that he thinks he has explained how the particles came to be grooved in that way.]

91. The particles coming from opposite poles are twisted in opposite ways.

Because they approach the centre of the heaven from opposite directions, i.e. some from its south pole and some from its north pole, while the vortex as a whole is spinning on its axis in only one direction, it's obvious that the particles coming from the south pole must be twisted in exactly the opposite direction from those coming from the north pole. This fact is pretty important, I think, because power of magnets depends on it, as I'll show later on, ·starting at 4:133·.

92. There are only three grooves in them.

93. The first element contains these striated particles, the tiniest particles, and other particles of various sizes.

94. How these particles produce spots on the surface of the sun and the stars.

95. This lets us discover the chief properties of these spots.

96. How the spots disintegrate, and new ones are produced.

97. Why the colours of the rainbow appear at the edges of some spots.

98. How spots are converted into bright areas, and vice versa.

99. The kinds of particles into which sunspots disintegrate.

100. How the ether round the sun and stars is produced from these particles. This ether and the spots belong to the third element.

101. The production and disintegration of spots depends on very uncertain causes.

102. How a single spot can cover an entire star.

103. Why the sun sometimes appears less bright, and why certain stars seem to change in size.

104. Why some fixed stars disappear or appear unexpectedly.

105. There are many passages in the spots through which the striated particles freely pass.

106. The arrangement of these passages, and why the striated particles can't return through them.

107. Why particles coming from one pole don't pass through the same passages as those coming from the opposite pole.

[Descartes's explanation of this, which is the central idea throughout sections 105–8, and in the Part 4 treatment of magnets, is the simple fact that a passage which snugly fits a right-handed corkscrew won't fit a left-handed one unless it approaches the passage from the other end.]

108. How the matter of the first element passes through these passages.

109. Other passages intersect them crosswise.

110. The light of such stars can scarcely pass through a spot.

111. Description of a star appearing unexpectedly.

112. Description of a star gradually disappearing.

113. In all spots there are many passages hollowed out by striated particles.

114. The same star can appear and disappear in turn.

115. It can happen that an entire vortex with a star at its centre is destroyed.

116. How it can be destroyed before many spots have gathered around its star.

117. How there can be many spots around a star before its vortex is destroyed.

118. How such a large number of spots is produced.

119. How a fixed star is changed into a comet or a planet.

120. The direction in which such a star moves when it first ceases to be fixed.

121. What we understand by the solidity of bodies, and their agitation.

[In this and the following few sections, Descartes introduces a new concept of 'solidity', defined in terms of 'the quantity of matter of the first element'. It would be unduly hard work to explain how it relates to other things he has said about solidity; and his use of it here suffers from being inextricably tied in with his theory about sun spots.]

122. Solidity depends not on matter alone but also on size and shape.

123. How celestial globules can be more solid than a whole star.

124. How they can also be less solid.

125. How some are more solid than a star and others less solid.

126. What sets a comet in motion.

127. The continuation of a comet's motion through various vortices.

128. Phenomena pertaining to comets.

129. The explanation of these phenomena.

130. How the light of a fixed star reaches the earth.

131. Whether the fixed stars are seen in their true locations; and what the firmament is.

132. Why comets are not seen by us when they are outside our heaven; and, incidentally, why coals are black and ashes white.

133. The tail of a comet and its various phenomena.

134. The type of refraction responsible for a comet's tail.

135. The explanation of this refraction.

136. The explanation of the appearance of the tail.

137. How beams of fire also appear.

138. Why the tail of a comet doesn't always appear in a direction directly opposite to the sun and doesn't always appear straight.

139. Why such tails don't appear around the fixed stars or planets.

140. What sets a planet in motion.

141–5. The five causes of deviations in planetary motions.

146. The initial formation of all the planets.

147. Why some planets are more remote from the sun; this doesn't depend on their size alone.

148. Why those nearer to the sun move faster, although the sun's spots move very slowly.

149. Why the moon revolves around the earth.

150. Why the earth rotates on its axis.

151. Why the moon moves faster than the earth.

152. Why very nearly the same face of the moon is always turned towards the earth.

153. Why the moon moves faster and diverges less from its mean motion in conjunction than in quadrature; and why its heaven is not round.

154. Why the secondary planets around Jupiter move so fast, while those around Saturn move so slowly if at all.

155. Why the poles of the equator and the ecliptic are so far apart.

156. Why they are gradually moving closer to one another.

157. The basic and most general cause of all the inequalities in the motions of the bodies in the universe.

Lastly, we shan't be surprised at the fact that all the planets, despite their constant tendency to move in a circular fashion, never follow perfect circles but are always subject to slight deviations of all kinds, both longitudinal and latitudinal. For all the bodies in the universe are contiguous and interact with each other, a vacuum being quite impossible, so that the motion of any one body depends on the motion of all the others, and hence is subject to countless variations. I think I have here given a satisfactory explanation of absolutely every phenomenon that we observe in the heavens above us. It remains for us to deal next with the phenomena we see here on earth.