ISAAC ASIMOV'S GUIDE TO EARTH AND SPACE

- How was the moon formed?
- What makes the wind blow?
- Is there life on Mars?

Find out in this thrilling tour of the cosmos.

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Isaac Asimov

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REACH FOR THE STARS. . . .

- How hot is the sun?
- Are the laws of nature the same everywhere?
- Is there life on planets circling other stars?
- Does anything reach us from the stars besides light?
- Is there a center of the universe?
- How old is the universe?
- What are quasars?
- Can we see the big bang?
- Will the expansion of the universe continue forever?
- Is there matter in the universe we can't see?

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many more questions, turn to
ISAAC ASIMOV'S
GUIDE TO EARTH AND SPACE.

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**Published by Fawcett Books*

TO KATE MEDINA

—together again

CONTENTS

INTRODUCTION

The physical world is a large and wonderful place, but it is also confusing, and there is much about it that no one quite understands. There are also many phenomena that some of us understand pretty well, but others do not.

One of the reasons that most of us don't know as much about the world as we might is simply that we don't bother to think about it. Which is not to say that we don't think at all. Everyone thinks, but each person tends to concentrate mostly on matters that seem to be of immediate importance. What shall we have for dinner? How do I pay my bills? Where shall I go for a vacation? How can I go about getting a promotion and a raise in pay? Shall I try to arrange a date with so-and-so? What's this funny pain I have in my side?

These are such important questions to each of us, and our need to answer them is often so strong that there is simply no time to wonder about more general issues such as: What is the shape of the Earth? A natural response to a question like this might be: "Who cares? Why do you bother me with such silly things? What difference does it make?"

But it does make a difference. For example, you can't sail a ship across the ocean and reach your destination by the shortest possible route, or fire a missile and expect it to land on its target, without knowing the shape of the Earth.

But aside from that, and far more important, is that wondering about such questions is fascinating, and finding the answers is fairly easy if you're systematic about it. The aim of this book is to bring these general questions closer to home, by exploring their answers in terms that anyone can follow, making the complexities of the universe absolutely clear.

Of course, one question usually leads to another. Knowledge about the world is not a straight line but an intricately connected three-dimensional lacework, so that answering a particular question sometimes requires an explanation of something else, which in turn demands the explanation of still another thing, and so on. I will, however, attempt to unravel the threads with as much care as possible so that not too much has to be explained at any one time. Nevertheless, it might still be necessary for me to jump about a bit now and then, and I ask forgiveness for that.

Then, too, as we advance from question to question, simple reasoning in some cases will not be enough; we will have to know a little about what scientists have observed and deduced. But I will try to describe that work with particular care and, wherever possible, without complex mathematics or diagrams. Thinking always leads to more thinking, and there's no end to it. To people who enjoy thinking, that is the glory of science. People who don't enjoy thinking about things that don't concern them immediately, find the necessity of continuing to do so indefinitely frightening, and they turn away from science. I hope you are in the first group.

So let us get started with the question I have already asked and see where that will take us.

1. WHAT IS THE SHAPE OF THE EARTH?

To begin with, we must look around us and see that the Earth is uneven and has no easily described shape. Even if we ignore houses and other man-made objects, and all living things as well, we are still left with an uneven surface of bare rock and soil.

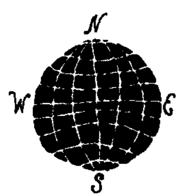
The first conclusion we would come to, then, would be that the Earth is a lumpy object with hills and valleys, cliffs and ravines. In places like Colorado, Peru, or Nepal, where there are towering mountains that reach miles into the air, the Earth's irregularity is very clear. But if you live in some parts of Kansas or Uruguay or the Ukraine, you don't see much in the way of hills or valleys; you see plains, which look pretty flat.

Then, too, even if you do encounter hills and mountains, the Earth may rise on one side, but then fall again on the other side. Valleys and ravines may slant down on one side, but slope up on the other. No part of the Earth's land surface goes up without ever coming down again as you move across it; no part goes down without ever going back up. It seems reasonable, then, to conclude that the Earth is, *on the average*, flat.

Again, if you were to paddle a boat out onto a body of water so large that you couldn't see land in any direction, you would have only the surface of the water to consider. This surface is uneven because it is full of waves. Yet if there is no wind, the waves are not large, and it is easy to see that, on the average, the water surface is flat. In fact, water is much more nearly flat at all times than land.

So it makes sense to suppose that the Earth is flat, and for thousands of years that is exactly what human beings believed. Since a flat Earth made sense and since it didn't take much thinking to see that it made sense, why would anyone waste any further time thinking about it?

Have you ever stood on a hilltop and looked out on the valley below? The valley looks pretty flat and you can look farther and farther outward, past houses, trees, rivers, and other faraway objects, though the more distant they appear to be, the less detail you can make out. What's more, the air isn't usually absolutely clear; bits of fog and smoke obscure the very distant portion, which becomes a kind of bluish haze where the Earth and sky seem to meet.



The meeting place of earth and sky is called the *horizon*, from a Greek word for *boundary*. If you're looking at a flat section of the Earth, the horizon runs evenly from right to left, and such a line is therefore called *horizontal*.

Suppose, however, that you look in another direction at another hill close by. You can't see past the top of the hill to the other side because you can't see around curves. Therefore as you look at the top of the hill, you see only the sky above it, and not the Earth sloping downward beyond it. There is a sharp line that seems quite close to you that marks off the hill against the sky. Thus, if you are looking out over a stretch of land and see a distant misty horizon, you know you are looking over some pretty flat territory, but if you see a sharp nearby horizon, you are looking at a hilltop.

Imagine that you are out on the ocean on the deck of a ship. It is a clear, bright, sunny day, and the sea is calm. The sea air is usually less dusty and misty than land air, so you look off into the distance, and there is the horizon—sharp. The sea meets the sky in a clear horizontal line. You are clearly looking at a hilltop.

How can that be? There are no hills in the ocean, just flat water. The only answer is that the ocean is not flat, but curved, and from your height on the ship deck, you can see out only so far till your eyesight meets the top of the curve, and you can't see beyond it. If you go up to a higher deck, you can see farther out before the curve cuts off your view, and if you go to a lower deck, you can see less far out. What's more, if you stand in one place and look all around you, you will see that same sharp horizon at the same distance in every direction; not only does the ocean surface curve, but it curves in the same way and to the same extent in every direction—at least as nearly as one can make out with the eyes.

But why should the ocean curve? It must be following the surface of the Earth, and the Earth itself must be curving in all directions, too. The curving is more obscure on the land because the land is more uneven than the sea, and the air over the land is usually mistier.

Given that the Earth does curve, what kind of curve is it? If the Earth curves in the same way in all directions, it must be a sphere, for that is the only known surface that curves downward equally in all directions. So just by looking and thinking we can see that the Earth is a sphere.

You might ask why people didn't study the horizons and come to this conclusion thousands of years ago, but the trouble is, few people thought about it at all. It was much simpler to think of the Earth as flat, and flatness didn't raise any particular problems in ancient times. A spherical Earth, as we shall soon see, does raise problems that require further thought.

You might ask: Can we trust our eyes? Is looking at the horizon enough? Actually, in this case it is, though we are frequently misled by our eyes, if we don't examine the evidence carefully.

For instance, suppose you are at sea and can identify a ship in the distance sailing toward the horizon. You watch it, and as it approaches the horizon, you don't see the lower decks anymore; then, after a while, you don't see the upper decks, either. All you see are the smokestacks (or the sails, if it is a sailing vessel), and then they disappear, too. It's not just a matter of distance, for if you had a spyglass and watched through that, the ship would seem much larger and closer, but you would still see it disappear first at the bottom, then higher up, then still higher. What you are seeing is the ship sailing over the top of the Earth's curve and down the other side.

The first person we know of who ever maintained that the Earth was a sphere was the Greek philosopher Pythagoras (c. 580–c. 500 B.C.), who came up with this hypothesis in about 500 B.C.

There are other pieces of evidence that show the Earth to be a sphere. Certain stars are visible from some points on Earth and not from others, and during an eclipse of the moon a shadow of the Earth falls on the moon that is always curved like the edge of a sphere. The Greek philosopher Aristotle (384–322 B.C.) listed all the evidence for the Earth's sphericity in about 340 B.C., and though it wasn't commonly accepted at the time, no educated man has doubted it since. In the Space Age of today, photographs have been taken of Earth from outer space in which we can actually *see* that it is a sphere.

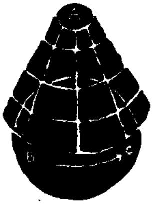
2. WHAT IS THE SIZE OF THE EARTH?

As long as people thought the Earth was flat, there was not much reason to worry about how large it was. It might stretch on forever, for all anyone knew, but *forever* is a hard concept to imagine. It was a lot easier to think that the Earth had a definite size and that there was some end to it somewhere. Even today, people speak of "traveling to the ends of the Earth," though nowadays that is only a colorful phrase and not meant to be taken literally.

Of course, the thought of an end to the Earth creates problems. Suppose you traveled a long distance and finally reached the end. Could you fall off? If the ocean stretched out to the end, might it pour off until it was all gone? People who bothered to think of such matters had to work out a way of keeping that from happening. Perhaps the world is rimmed by a solid bank of tall mountains, so that it looks like a frying pan and nothing on the surface can fall off. Or perhaps the sky is a piece of solid matter that is curved like a flattened hemisphere (which is what it looks like) and it comes down to meet the Earth on all sides, so that the Earth is a flat plate with a lid on it—that, too, would keep things in place. Either solution seemed satisfactory.

You might still ask how large the flat world was. In very ancient times, when people could move about only on foot and didn't travel much, it was assumed that the world was quite small and that only one's own region existed. That is why when, in 2800 B.C., there was a tremendous river flood in the Tigris-Euphrates river valley, the Sumerians who lived there thought the entire world was covered, and that naïve notion has come down to us as the biblical tale of Noah's flood.

As people learned to trade, however, and sent armies hither and yon, and took to riding horses, the horizon of the world expanded, and by 500 B.C., the Persian Empire stretched out from east to west over a distance of 4,800 kilometers (3,000 miles).* West of that empire were Greece, Italy, and other lands, and there was no sign of an end.



When the Greek philosophers realized that the Earth was a sphere, however, they knew it had to have a definite size, and you couldn't get away with just saying that it was "very large" or that it went on and on "indefinitely." What's more, the size of the sphere could be judged without necessarily going very far from home.

You see, whereas a flat Earth can stretch out indefinitely, a spherical Earth curves, and the curve must come back on itself. To determine the Earth's size, all you have to do is measure how much it curves; the more sharply it curves, the smaller the sphere, and the more gently it curves, the larger the sphere.

One thing we can be sure of is that the curve is very gentle, so that the sphere is very large. We know this must be so simply because it took so long to decide the Earth was spherical. If the sphere was small, the curvature would be so sharp that it would be impossible not to notice it. The gentler the curvature, the flatter a small region of the Earth would seem.

But how do we measure the extent of the curvature of the Earth?

Here's one way. Take a thin strip of metal and force it down on an absolutely level stretch of the Earth, so that it touches the Earth at all points. It will then be forced to follow the curve of the Earth. You can then lift that strip of metal and sight along it and see how much it has curved downward. If the strip of metal is 1 kilometer long, then its downward curve should be about $12\frac{1}{2}$ centimeters (5 inches—for 1 centimeter, which is equal to $\frac{1}{100,000}$ of a kilometer, is equal to about $\frac{2}{5}$ of an inch).

The trouble with taking this measurement is that it would be hard to find a kilometer of Earth's land surface that was

*I shall use the metric system in this book and give distances in kilometers, but I will place American units in parentheses. One kilometer is equal to just about five eighths of a mile. The metric system is used over the entire world *except* the United States.