Forrest Mims III

Make: Forrest Mims' Science Experiments

DIY Projects from the Pages of Make:

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Forrest Mims' Science Experiments
DIY Projects from the Pages of Make:
By Forrest Mims

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Dedication

This book is dedicated to my late father, Forrest M. Mims Jr., and my wife Minnie, both of whom encouraged my pursuit of science, and our three children, Eric, Vicki and Sarah, each of whom produced outstanding science fair projects during their school years.

Acknowledgments

This book owes much to former *MAKE:* Magazine editor Mark Frauenfelder, who understands better than anyone the motivations that drive and inspire both makers and amateur scientists. It was Mark who assigned the column in *MAKE:* that evolved into this book.

Contents

Preface vii

1 How to Study Tree Rings 1

2 Snow Science. 7

3 Tracking Heat Islands 15

4 Vibration Sensors 21

5 Make an Experimental Optical Fiber Seismometer 27

6 Ultra-Simple Sunshine Recorders 33

7 The Infrared Thermometer: An Essential Science Gadget 39

8 Capturing and Studying Airborne Dust, Smoke, and Spores 47

9 Track the Leading Greenhouse Gas 55

10 Build a Twilight Photometer, part 1 63

11 Build a Twilight Photometer, part 2 71

12 How to Analyze Scientific Images 77

13 Doing Science with a Digital Scanner 83

14 Data Mining: How to Analyze Online Scientific Data 91

15 Using Sensors with Dataloggers 99
16 How to Document What You Make or Discover . . 107
17 MARS-BOT: Adding Science to Robotics 113
18 How to Photograph the Solar Aureole 119
19 Record Your World from a Picture Post 125
20 Digital Pinhole Photography 133
21 How to Make and Use Retroreflectors 141
22 How to Use LEDs to Detect Light 147
23 Use LEDs to Track Night-Launched Projectiles . . 153
24 Connecting Fibers to LEDs and Sensors 159
25 Transform Things into Sounds with the PunkPAC . 165
26 Making Synthesized Music from Your Data 173
27 Startups: Origins of the PC Revolution 181
28 Thomas Jefferson: Maker in Chief 183
29 The Kit That Launched the Tech Revolution. . . . 193
30 When Projects Fail 199
Index 205

Preface:

Becoming an Amateur Scientist

An editorial in a leading science journal once proclaimed an end to amateur science: "Modern science can no longer be done by gifted amateurs with a magnifying glass, copper wires, and jars filled with alcohol." I grinned as I read these words. For then as now there's a 10× magnifier in my pocket, spools of copper wire on my workbench, and a nearby jar of methanol for cleaning the ultraviolet filters in my homemade solar ultraviolet and ozone spectroradiometers. Yes, modern science uses considerably more sophisticated methods and instruments than in the past. And so do we amateurs. When we cannot afford the newest scientific instrument, we wait to buy it on the surplus market or we build our own. Sometimes the capabilities of our homemade instruments rival or even exceed those of their professional counterparts.

So began an essay about amateur science I was asked to write for *Science* (April 1999, http://science.sciencemag.org/content/284/5411/55.full), one of the world's leading science journals. Ironically, the quotation in the first sentence came from an editorial that *Science* had previously published.

In the years since my essay appeared in *Science*, amateur scientists have continued doing what they've done for centuries. They've discovered significant dinosaur fossils, found new species of plants, and identified many new comets and asteroids. Their discoveries have been published in scientific journals and books. Likewise, thousands of websites detail an enormous variety of amateur science tips, projects, activities, and discoveries. Ralph Coppola has listed many of these sites in "Wanderings," his monthly column in *The Citizen Scientist* (www.wanderings.ca/TNW/Archive/Wanderings.pdf).

Today's amateur scientists have access to sophisticated components, instruments, computers, and software that could not even be imagined back in 1962 when I built my first computer, a primitive analog device that could translate 20 words of Russian into English with the help of a memory composed of 20 trimmer resistors (www.digibarn.com/stories/MITS/forrest-mims-III-material/Homebrew%20Analog%20Computer.pdf).

Components like multiwavelength LEDs and laser diodes can be used to make spectroradiometers and instruments that measure the transmission of light through the atmosphere. Images produced by digital video and still cameras can be analyzed with free software like ImageJ to study the natural world in ways that weren't even imagined a few decades ago. Amateur astronomers can mount affordable digital cameras on their telescopes, which then scan the heavens under computer control.

Cameras, microscopes, telescopes, and many other preassembled products can be modified or otherwise hacked to provide specialized scientific instruments. For example, digital camera sensors are highly sensitive to the near-infrared wavelengths beyond the limits of human vision from around 800nm–900nm. IR-blocking filters placed over camera sensors block the near-IR so that photographs depict images as they'd be seen by the human eye. Removing the near-IR filter provides a camera that can record the invisible wavelengths reflected so well by healthy foliage.

Many of the makers who publish their projects in the pages of *MAKE, Nuts and Volts*, and across the web have the technical skills and resources to devise scientific tools and instruments far more advanced than anything my generation of amateur scientists designed. They also have the ability to use these tools to begin their own scientific measurements, studies, and surveys. Thus, they have the potential to become the pioneers for the next generation of serious amateur scientists.

This book covers some of the many ways you can enter the world of amateur science. For now I'll end this chapter with a brief account of how I began doing serious amateur science, so you can see how a relatively basic set of observations of the atmosphere has lasted more than 20 years and, with any luck, will continue for another 20 years.

Case Study: 20 Years of Monitoring the Ozone Layer

In May 1988, I read that the U.S. government planned to end a solar ultraviolet-B radiation-monitoring program due to problems with instruments. Within a few months I began daily UVB monitoring using a homemade radiometer. The radiometer used an inexpensive op-amp integrated circuit to amplify the current produced by a UV-sensitive photodiode. An interference filter passed only the UVB wavelengths from about 300nm–310nm, while blocking the visible wavelengths.

I described how to make two versions of the UVB radiometer in "The Amateur Scientist" column in the August 1990 *Scientific American*. This article also described how the radiometer detected significant reductions in solar UVB when thick smoke from forest fires at Yellowstone National Park drifted over my place in South Texas in September 1988.

FIGURE P-1. Scientist Brooke Walsh measures the ozone layer with the world-standard ozone instrument at Hawaii's Mauna Loa Observatory, which Forrest Mims calibrated at the same location during summer 2016.

Ozone strongly absorbs UV, and you can determine the amount of ozone in a column through the entire atmosphere layer by comparing the amount of UV at two closely spaced UV wavelengths. This is possible because shorter wavelengths are absorbed more than longer wavelengths.

This meant that my simple UVB radiometer formed half of an ozone monitor. So I built two radiometers inside a case about half the size of a paperback book. One radiometer's photodiode was fitted with a filter that measured UVB at 300nm, and the second was fitted with a 305nm filter. I named the instrument TOPS for Total Ozone Portable Spectrometer. (Full details are at http://forrestmims.org/images/SCIENCE_PROBE_TOPS_PROJECT_NOV_1992_small.pdf.)

TOPS was calibrated against the ozone levels monitored by NASA's Nimbus-7 satellite. This provided an empirical algorithm that allowed TOPS to measure the ozone layer to within about 1% of the amount measured by the satellite. During 1990, ozone readings by TOPS and Nimbus-7 agreed closely. But in 1992, the two sets of data began to diverge so that TOPS was showing several percent more ozone than the satellite.

When I notified the ozone scientists at NASA's Goddard Space Flight Center (GSFC) about the discrepancy, they politely reminded me that the satellite instrument was part of a major scientific program and not a homemade instrument. I responded that I had built a second TOPS and both showed a similar difference, but this didn't convince them.

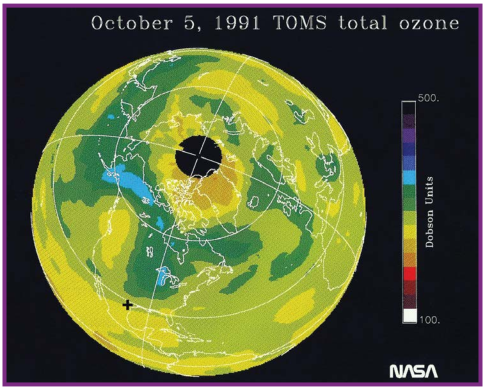

FIGURE P-2. This global ozone image was acquired while NASA's Nimbus-7 satellite was providing accurate data during 1991. On this day TOPS-1 measured 284.4 Dobson units (DU) of ozone, and the satellite measured 281.5 DU.

During August of 1992, I visited Hawaii's Mauna Loa Observatory for the first time to calibrate my instruments at that pristine site 11,200 feet above the Pacific Ocean. The world-standard ozone instrument was also being calibrated there, and it indicated a difference in ozone measurements made by Nimbus-7 that were similar to what I had observed.

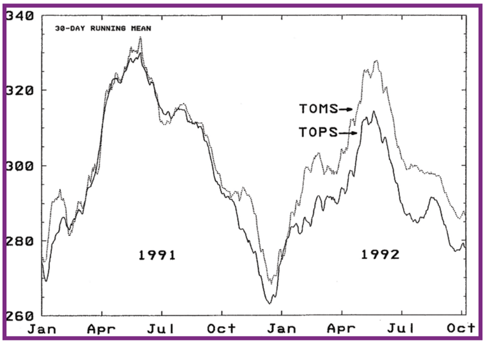

FIGURE P-3. Plot compares ozone measurements by TOPS and Nimbus-7. In 1992, the calibration of the satellite's instrument began to drift.

Eventually NASA announced that there was indeed a drift in the calibration of its satellite ozone instrument. A paper I wrote about this sparked my career as a serious amateur scientist when it was published in *Nature*, another leading science journal ("Satellite Ozone Monitoring Error," page 505, Feb. 11, 1993).

Later GSFC invited me to give a seminar on my atmospheric measurements titled "Doing Earth Science on a Shoestring Budget." That talk led to two GSFC-sponsored trips to study the smoky atmosphere over Brazil during that country's annual burning season, and several trips to major forest fires in the western U.S.

Going Further

The regular ozone measurements I began on Feb. 4, 1990 have continued to this day along with measurements made by various homemade instruments of the water vapor layer, haze, UVB, and other parameters. In future chapters we'll explore how you can also make such measurements—and make discoveries of your own.

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Rolex Awards For Enterprise, 1993, this certifies

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is hereby publicly acclaimed as one of the five international
of The Rolex Awards For Enterprise, 1993, for seeking to break new

FIGURE P-4. The TOPS project earned a 1993 Rolex Award that provided funds for the development of a first-generation micro-processor-controlled TOPS (Microtops) by Scott Hagerup.

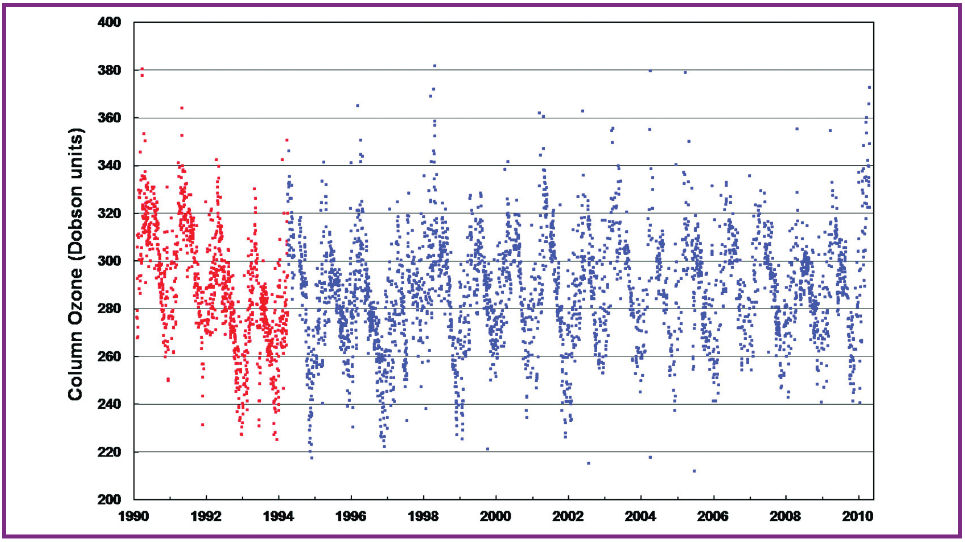

FIGURE P-5. The ozone layer over South Texas, measured by the author. Red points from 1990 to 1994 were measured by TOPS-1. Blue points from 1994 to 1997 were measured by Microtops and Supertops. Points from 1997 to 2010 were measured by Microtops II, manufactured by Solar Light.

How to Study Tree Rings

In this chapter you'll find projects that hopefully will encourage you to begin doing science, whether you're a student looking for a good science fair project or an adult wanting to start personal science study.

Tree Rings

In temperate and arctic regions, most trees are dormant during winter. When spring arrives, a sudden burst of growth expands trunks and branches with new wood, known as early wood (or spring wood), formed from large cells.

As the growing season peaks, the growth slows, and the late wood (or summer wood) that forms has cells with thicker walls. This late wood may appear much darker than the early wood when it contains more tannin (Figure 1-1).

FIGURE 1-1. Cross-sections from two varieties of bald cypress felled by a Texas flood.

Each year, this process forms a new growth ring, just beneath the bark of the trunk and branches of a tree.

Not all trees produce annual growth rings. Trees in the tropics that grow year round may have very suppressed annual rings or none at all. I learned this firsthand while sampling trees in Brazil during a field trip sponsored by NASA to measure the impact of severe biomass smoke on the atmosphere and plants.

Where I live in Texas, most trees are dormant during winter. But only some of these trees produce sharply defined rings. These include the red oak, hackberry, and all pine and bald cypress trees (Figure 1-2). The live oak keeps its leaves during the winter, and its rings can be difficult to count.

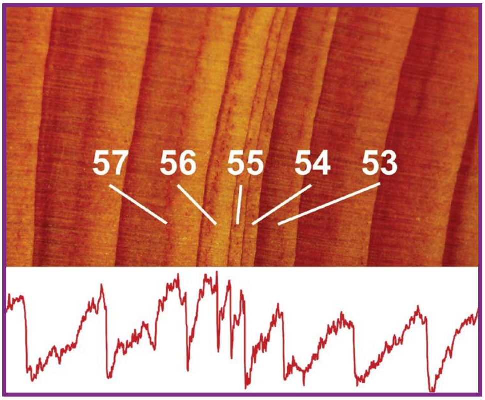

FIGURE 1-2. Narrow rings in this bald cypress accompanied a 1950s drought; ring chart by ImageJ software.

The Science of Tree Rings

Astronomer A. E. Douglass established tree ring science when he postulated that tree growth was influenced by climate changes caused by the solar cycle. He developed and taught classes at the University of Arizona on dendrochronology, the science of dating trees by studying their rings. In 1937, he established the university's Laboratory of Tree- Ring Research.

Douglass showed that archaeologists could use growth rings to date the timbers used to build ancient structures. Annual growth rings in trees also provide valuable information about past precipitation, climate, major volcano eruptions, and forest fires (Figure 1-3). They permit long-ago floods and landslides to be dated.

FIGURE 1-3. Century-old Norway spruce felled by chainsaw.

How to Obtain and Prepare Tree Ring "Cookies"

You can learn to do tree ring studies by using slices, or "cookies," cut from trunks and branches. Christmas trees are an excellent source, as are building and road construction sites. Professional tree trimmers and landscape crews may be willing to provide you with samples. Firewood may also provide good sample material. Another way to find samples is to keep an eye out for piles of recently cut and discarded branches.

You can even use cross-sections sawn from lumber, although these will not form round cookies. If you use this method, try to find dated lumber that includes the outer edge of the original trunk so you can determine the age of the rings.

If you have trees or access to trees where you live, you can cut branches or collect cores from trunks. If you're not the landowner, be sure to get permission first. This is especially important if you want to obtain samples from trees on private land or land owned or managed by cities, states, or the federal government.

FIGURE 1-4. This sequence of "cookies" cut from a branch at the top of a fallen pine tree allows its growth to be carefully analyzed.

When possible, use a sharp, fine-toothed wood saw to slice cookies from branches and trunks.

Living wood should be allowed to dry for a day or two before smoothing it with sandpaper. I usually begin with 100-grit sandpaper followed by 220 grit. The final polish is made with 400 or 600 grit.

Samples cut with a chainsaw can be used, but they'll require much more surface preparation. If possible, smaller samples cut with a chainsaw should be recut with a handsaw. You can use a power sander to smooth the rough faces of these samples.

For small samples, I prefer to use a handheld plane such as the Stanley 21-399 5-Inch Surform Pocket Plane. This tool will quickly remove burrs and other saw marks.

Large trunk cross-sections require considerable time to prepare (Figure 1-4). A local cabinet shop once smoothed some large bald cypress sections that I had used a chainsaw to remove from trees knocked down by a major flood. But the cabinet shop couldn't handle the largest section, which was more than three feet across.

How to Examine and Photograph Tree Ring Samples

Your sample is ready when it's been sanded smooth to the touch and has few remaining saw marks. If the polished side of the sample looks good, flip it over and use a ballpoint pen or fine-point Sharpie marker to write the species and the date and place where it was collected.

It's best to examine the rings with a magnifying lens or a 10x loupe. Note that individual rings may be dark on the side nearest the bark and light on the side nearest the center. Be careful to count these two differences in shading as one ring and not two (Figure 1-5).

The first thing I do is count the rings by their year, beginning from the first one inside the bark. You may want to place a mark at each tenth year. Ideally, try to determine the date when the branch or trunk began growing. After you determine this date, print it on the backside of the sample.

Professional tree ring analysts use various stains to highlight rings that are faint and difficult to see. You can even use water. Just moisten a paper towel in water and lightly stroke it across the sample.

FIGURE 1-5. This Norway spruce log was used to build a cabin in Switzerland. Experienced dendrochronologists can compare these rings with those of logs with known dates to determine when this log was cut.

FIGURE 1-6. You may need permission to take tree "cookies" across international borders, so take photos.

You can make photographs or digital scans of your tree ring samples for more detailed analysis and for display online. I've used scanners and digital cameras with a close-up setting. Try moistening samples as described above to enhance visibility.

Because of international travel restrictions, if you collect samples outside your country it's best to leave them behind and bring home only their photos (Figure 1-6).

You can use various photo processing programs to further enhance the visibility of the rings. And you can use ImageJ and other image analysis tools to help count the rings and study their color differences. ImageJ requires no license, and the program is freely available at http://rsbweb.nih.gov/ij/index.html. (See Chapter 12, "How to Analyze Scientific Images" for more about ImageJ.)

Going Further

There are some excellent websites devoted to tree rings. By far the most comprehensive is Dr. Henri D. Grissino-Mayer's Ultimate Tree-Ring Web Pages at http://web.utk.edu/~grissino/. This site includes a superb collection of tree ring images, background information, tips, and links to other tree ring sites (Figure 1-7).

Tools known as increment borers are used to extract cores of wood from living trees without having to cut down the tree. Suppliers of these tools are listed on the Ultimate Tree-Ring Web Pages. In my experience, an increment borer can never replace a full cross-section, but they're invaluable when cross-sections of trunks are simply unavailable. These tools are much easier to use in conifers than in hardwood trees, as I found out while working up a sweat coring hardwoods in Brazil's Amazon basin.

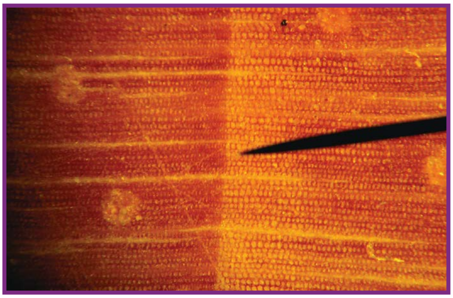

FIGURE 1-7. This microscope view shows the boundary between two growth rings in a pine branch cut by landscapers at Mauna Kea State Park in Hawaii. Growth is from left to right.