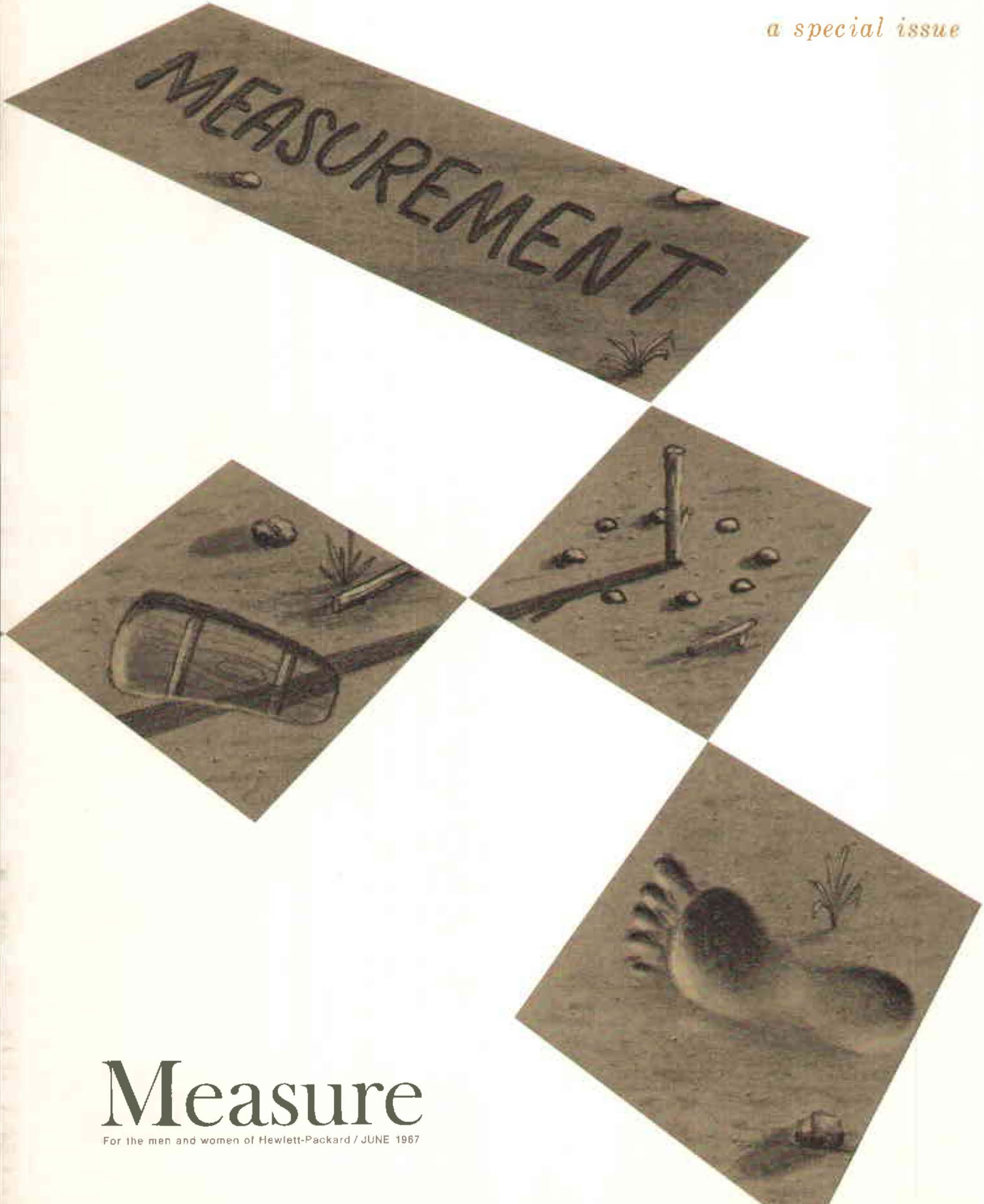
a special issue



Measure

For the men and women of Hewlett-Packard / JUNE 1967

"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind . . ."

LORD KELVIN (1824-1907)

Coming: MEASUREMENT'S NEW DIMENSION

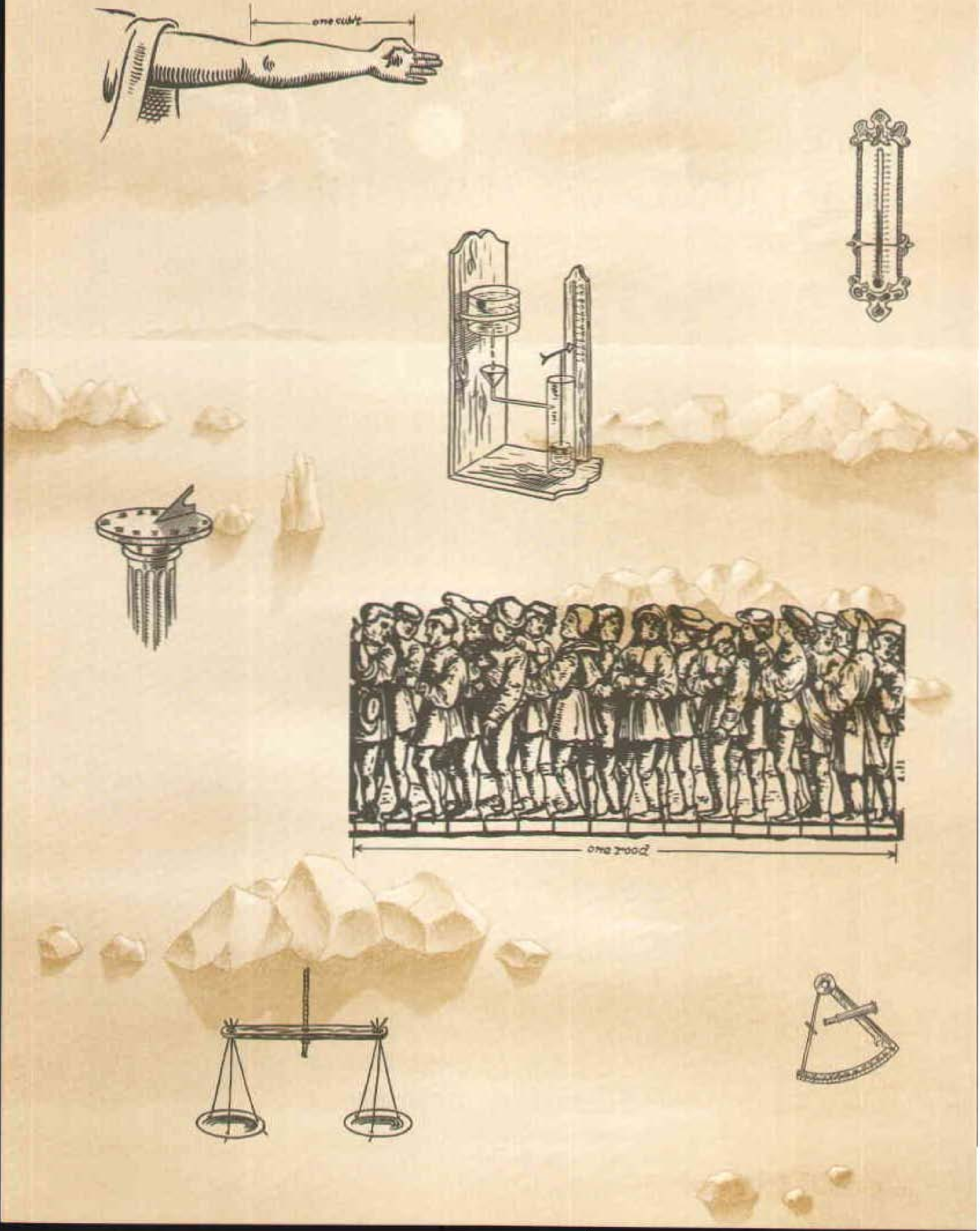
Any nanosecond now, you can expect to see another revolution take place in the art and science of measuring. Look what the last measurement revolution — call it the first electron revolution — did. Gave us a whole new medium for observing and recording events. Out of the lab went the cuckoo clock measuring device with all its springs, levers, spokes, and sprockets. In came the electron tube, the semiconductor diode, the transistor—and now, the integrated circuit and its successor, large-scale circuit integration.

What a job the electron revolution took on! At last estimate for the U.S. alone, electronic measurements were a significant and growing part of the more than 20 billion measurements being made each day throughout the country.

The systems of measurement in use to do this job have been valued at more than $25 billion, with almost $5 billion being added each year.

Something else happened. Thanks largely to the power which electromagnetic techniques lend to the process of learning, measurement has begun to take on an identity of its own, whether practiced in the laboratory, the school, the hospital, the factory, or the defense facility. As the awesome importance of measurement became appreciated, many experts have taken a new look at its historic role. They have concluded most soberly that it must be recognized as a key index of the vitality and sophistication of a civilization.

Then what is the coming revolution all about? Like the recent revolution, it will be electronic. But it will be more than just the introduction of increasingly sophisticated instrumentation. Rather — with the computer at its center — it will add a new dimension to man's ability to observe, to see meaning, and to control his universe.


one cubit
one rood

IN THE BEGINNING

Stirred in the earth's primordial atmosphere, the soup of life cooked slowly. A billion years of baking in the sun's radiation brought forth the first simple organic compounds. Another two billion years of simmering in the seas yielded animate life that multiplied and diversified into an ocean of living forms. In this upward spiral, those that survived did so by virtue of superior adaptation — nature's own measuring system.

Measurement seems instinctive to much of life. Perhaps we may say that instinct is in good part the ability to measure — to recognize and respond "naturally" to the dimensions of things without mental debate or deliberation.

Instinctive measurement is the bee returning to the hive after a successful hunt for food: the steps of the mindless dance he performs tells the assembled throng that his find is located in a certain direction and at a certain distance measured by some inner clock during his return flight.

Instinctive measurement is the chameleon, swivelling his turreted eyes into binocular vision to get a victim's range, then shooting his adhesive tongue out to almost twice his body length to pick off the unwary prey.

Instinctive measurement is that night flyer, the bat. His acute ultrasonic sending and receiving system easily guides his flight in total darkness through mazes of branches and other obstacles, and helps locate his fluttering food supply.

It took early mankind eons to triumph over instinct. When finally his growing intelligence allowed him to perceive the relationship between cause and effect, he created tools and weapons. These sticks and stones, or combinations thereof, doubled handily as the first measuring devices.

A stone's throw could set the boundary of a perimeter defense system. A chief's stick could serve as an arbitrary but reproducible standard of length in setting property lines.

A stone could serve equally well as a standard weight. Hollowed out, it could provide a measure of volume. And a stick stuck in the open ground casts a moving shadow — probably the first clock.

As one might expect, it was the Egypt of 5,000 years ago that devised the first master system of linear measurement. Responding to new needs, which appeared because Egypt had developed a social order of unparalleled complexity, the pharoah ordered up the royal cubit. For reference, it used the pharoah's forearm. The royal standard was fashioned of black granite "to endure for all time." For universal use and accuracy, working copies of the cubit were to be compared and calibrated "at each coming of the full moon." It measured 20.67 inches in length, and was subdivided into increments as small as 1/448th. Without the royal cubit none of Egypt's achievements in monumental construction, irrigation, or land taxation would have been possible, nor would the culture that came with them.

The Egyptian idea of standards for weights and measures spread to Greece, to Rome, and throughout the known world. Then, 1,500 years ago, standardization largely disappeared along with the Roman Empire.

Under the shadows of the Dark Ages, near-chaos prevailed. Every parish and every guild of tradesmen adopted its own system. It was quite acceptable in the mood of that day for a treatise on surveying by Koebel to issue the following instruction on establishing a "rood": "Stand at the door of a church of Sunday and bid 16 men to stop, tall ones and small ones, as they happen to pass out when the service is finished; then make them put their left feet one behind the other, and the length thus obtained shall be a right and lawful rood to measure and survey the land with, and the 16th part of it shall be a lawful foot."

Hence, also, the "mile" from the Latin for 1,000 paces (2 steps each), the "furlong" for a furrow running the length of the medieval acre, the English "yard" extending from the point of Henry I's nose to the tip of his thumb, the "inch" measured against the length of three dry barleycorns, the "troy" pound based on the weight of 5,760 grains of wheat as counted by the precious metal merchants of Troyes, France, and the "avoirdupois" pound, with its 7,000-grain basis.

The history of scientific measurement in these years was no less dismal than that of commercial and household measurement.

The mathematical findings of Pythagoras, the mechanical principles of Archimedes, and the accurate earth-measuring techniques of Eratosthenes became lost or frozen for over a thousand years. Ironically, the astronomy of Hipparchus and Ptolemy, who theorized and "proved" a universe with earth as its center, became popular, and enjoyed 1,300 years of unchallenged acceptance.

Meanwhile, clocks of increasing elaboration and accuracy were being developed. Originally, man had looked to the skies as an aid in his time telling and direction finding. As he became caught up in the mysteries of the stars, his view turned back to the clock to help improve his cosmic understanding. The "Dial of Ahaz" was the first recorded sun dial.

Then there was the water thief — the "clepsydra" of Babylon and Egypt. By steadily dripping water out of a small hole, elapsed time could be measured by noting the markings on the vessel's side. Later, ingenious improvements made it useful for telling the time of day as well as measuring elapsed time.

The clepsydra evolved into a finely turned and embellished instrument whose standard of workmanship became a tradition in clockmaking.

Its companion piece, the sand-filled hour glass, never became more than a simple device to be used mainly as a portable time teller.

The French monk Gerbert is credited with devising the first known truly clock-like machine. The year was 990 A.D., and since many theologians were anticipating an end to the world in 10 years' time, they regarded this clock as a device of the devil, and so banished the inventive Gerbert.

Europe's oldest mechanical clock, the de Dondi masterpiece built in 1362, used extremely complicated gears that not only told time but recorded the movements of the sun, Mars, and Venus.

The famed de Vick clock, built in the French royal palace in 1364, introduced the first inertial mechanism — the first "tick-tock." Later came the pendulum, whose principles were delineated by Galileo, then the "Nuremberg Eggs" vest pocket watches of 1500. The modern mechanical clock was on its way.

Navigation was one of the principal spurs to accurate timekeeping. For centuries sailors had measured direction with comparative ease using the stars, the astrolabe, the sextant, and later the compass. These methods could accurately give latitude — one's distance from the nearest pole. But determining position was another matter. This requires knowledge of longitude — the east-west dimension — and for this one must measure time accurately. For decades the British Crown held out an offer of a fortune to the man who could develop a method of determining longitude within 30 miles at any time during a long sea voyage. In 1792 John Harrison was able to claim the award with a chronometer whose error could be determined within one-half second a day.

At about the same time the Nuremberg Eggs were hatched, the great becalmed mainstream of scientific endeavor began to flow again. Copernicus revised Ptolemy's creaking celestial theories. Then, in 1609, Galileo focused his telescope on the heavens. It was a double play that helped usher in the beginning of optics. Almost simultaneously, Kepler was framing a new picture of the solar system that set the pattern for future astronomers.

Freed from the numbing concept of a fixed and finite universe, men began to look more closely at the world around them in a spirit of scientific inquiry, and to measure what they found.

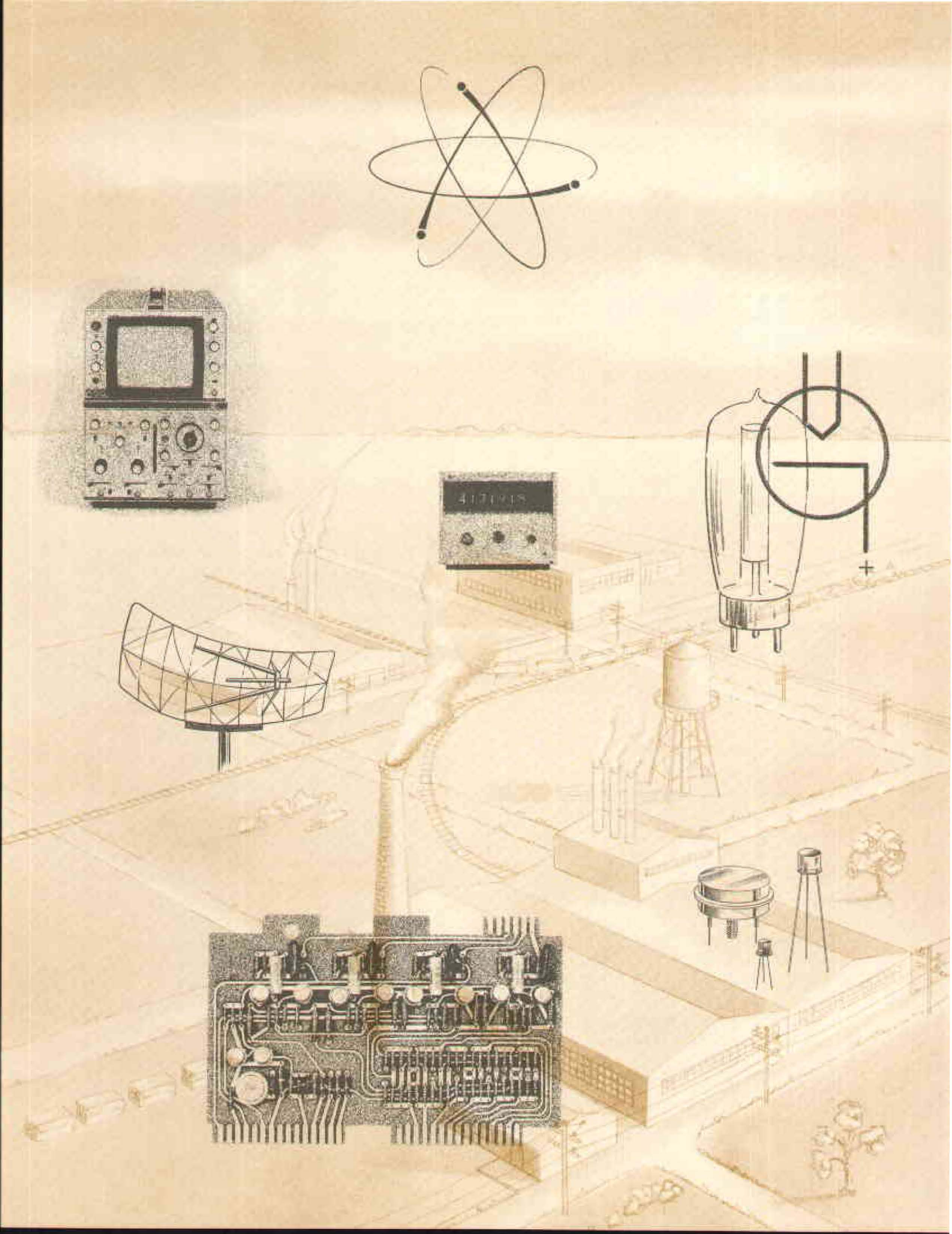
Many men contributed, and many such as Fahrenheit, Mach, Ohm, and Watt gave their names to the units of measurement with which they were identified. In its turn, measurement contributed mightily to the economic, social, industrial and political transformation of Western civilization. Accurate measurement had to come before the ensuing industrial revolution could come about, and certainly had to be widely available before mass production could appear. Some hint of measurement's importance may be seen in the efforts that were invested in the establishment of national and international standards for weights and measures.

Perhaps the most important attempt to clean up the measurement mess left by departing Roman legions was made in seventeenth century Paris when Jean Picard devised the metric system. More than a century later, in 1799, France passed a law establishing Picard's meter as 1/10,000,000th of the distance between the earth's poles and the equator. Large expeditions, akin in scale to the International Geophysical Year ventures of 1961-62, were launched to make the necessary observations along a line running from the North Pole through Paris to Equatorial Africa. But the effort ran into trouble. Science came to the rescue in 1892 when, based on Albert Michelson's discoveries, the meter's length was set in terms of the wave length of incandescent cadmium light.

Science notwithstanding, old ways persisted, even in France which made the metric system compulsory in 1801. Legislators of both the United States and Great Britain failed time after time to pass bills formally imposing the metric system. Finally, and expediently, its use was made legal for anyone so wishing — its present status in these countries.

In the United States of 1900, another landmark in measurements was established: the National Bureau of Standards.

Bursting with industrial vigor and a population of 76 million, turn-of-the-century America was ripe for the near-miracles which could emerge from new measuring abilities. Just around the corner . . .



ERA OF THE ELECTRON

Though most people tend to regard the scientific measurement revolution as a bright and shining product of the 20th century, it actually springs from men who were contemporaries of Abraham Lincoln. In fact, during the years from 1831 to 1865 a whole series of flashing scientific insights produced basic quantitative relations between electric and magnetic fields.

Not only scientific measurement, but also radio, television, and other inventions broadly useful to people, could not have come forth without these deep theoretical understandings.

While Michael Faraday (1791-1867) was the first to think of electromagnetism in the modern way, it remained for Karl Friedrich Gauss (1777-1855) to formulate the relations mathematically. Perhaps the greatest achievement in 19th century physics, however, was that of James Clerk Maxwell (1831-1879). The Maxwell differential equations, which relate the fundamental electric and magnetic fields, led immediately to the death of an old and crippling misconception, and the discovery of a profound new insight. The old notion was that of "action at a distance," the idea that a change in an electrical effect is instantly effective elsewhere. The new insight was that such changes spread out as a wave, at the speed of light — and, indeed, that electromagnetic waves are identical with light. Quickly there followed the discovery of the electron.

Now the point of departure had been reached for modern electronics as a branch of technology. Meaningful measurements were possible, and with them, understanding, invention, and control.

X-rays for medicine and radio for communication were among the first useful inventions to arise from the new science. Radio grew from Lee De Forest's 1906 discovery that the flow of large currents through an electron tube can be controlled by very small currents in a wire grid placed in the path of the electrons. Now, small forces, such as the sound of a man's voice, could control the high powers needed to generate and transmit radio waves or long-distance telephone calls.

Nevertheless, throughout the '20s and '30s, engineers heard more than talk and music in the waltz of the electrons. The oscilloscope was invented, so the shape of electrical signals could be seen as well as measured. Frequencies higher than those of broadcast radio became measurable and controllable. Out of this came early television and an electronic instrument of war — radar.

It was quickly learned that many non-electrical effects can be measured best by electronic means. The speed, convenience, and precision with which electronic devices can give information led to invention of new electronic devices which are better able than earlier instruments to measure time, distance, force, direction, temperature, chemical effects, and functions of the human body, to name only some.

Toward the end of the 1930s, Dave Packard and Bill Hewlett (young electrical engineers from Dr. Frederick E. Terman's Stanford laboratories, which also trained such men as the Varian brothers and William W. Hansen, frontrunners of modern microwave electronics) tinkered with a number of items before developing, in 1938, their first electronic instrument. This was a resistance-capacitance audio oscillator based on academic work by Hewlett. Included among its qualities were reliable performance, with high quality and simplicity. These characteristics became a hallmark of all HP products, many of which could measure things never before measured and others which made difficult measurements much easier.

As a result, advanced forms of measurement no longer were confined to a few select laboratories. Instead, large numbers of engineers and technicians were able to expand their contributions, individually and collectively, far beyond their previous potential.

Electronic voltmeters were other highly successful early Hewlett-Packard instruments. The trouble with previous voltmeters was that they tended to draw so much current from the object they were measuring that they altered the voltage being measured. Elaborate and, at the time, costly and finicky vacuum tube amplifiers minimized the effect. To overcome these problems, HP vacuum tube voltmeters ingeniously used "bridge" and "feedback" principles in ways which reduced complexity, relieved the meter of the need for frequent recalibration, improved accuracy, and reduced cost. HP descendants of these meters are still in wide demand. Semiconductors have, of course, replaced vacuum tubes in the later examples.

Using many of the same principles, and always with the same aims in mind, Hewlett-Packard engineers developed instruments to measure fidelity (the first distortion analyzers) and to make detailed study of waves and vibrations (the wave analyzers).

What was eventually to prove one of HP's most important and popular instruments first appeared in 1950. This was the high-speed electronic counter that was 100 times faster than earlier counters. Now accurate count could be made of events which occurred at rates as high as 10 million times a second. Later improvements raised the rate capability of HP counters to 100 million, then 500 million, and more recently to more than 12 billion per second.

HP's further contributions have included oscilloscopes which measure broader bands of frequency than any before, a spectrum analyzer which "sees" more (and more easily) than its predecessors, and a clock so accurate it can be used to compare national time standards, yet so light it can be carried around the world to make the comparisons.

Instruments answer questions, quickly and accurately. One way to see how this affects all our lives today is, perhaps, to ask how instruments will affect the future. In what directions, in fact, is the measurement art advancing? There is evidence the change will be in kind, not just in quality. A revolution, no less . . .

Measurements are based on standards

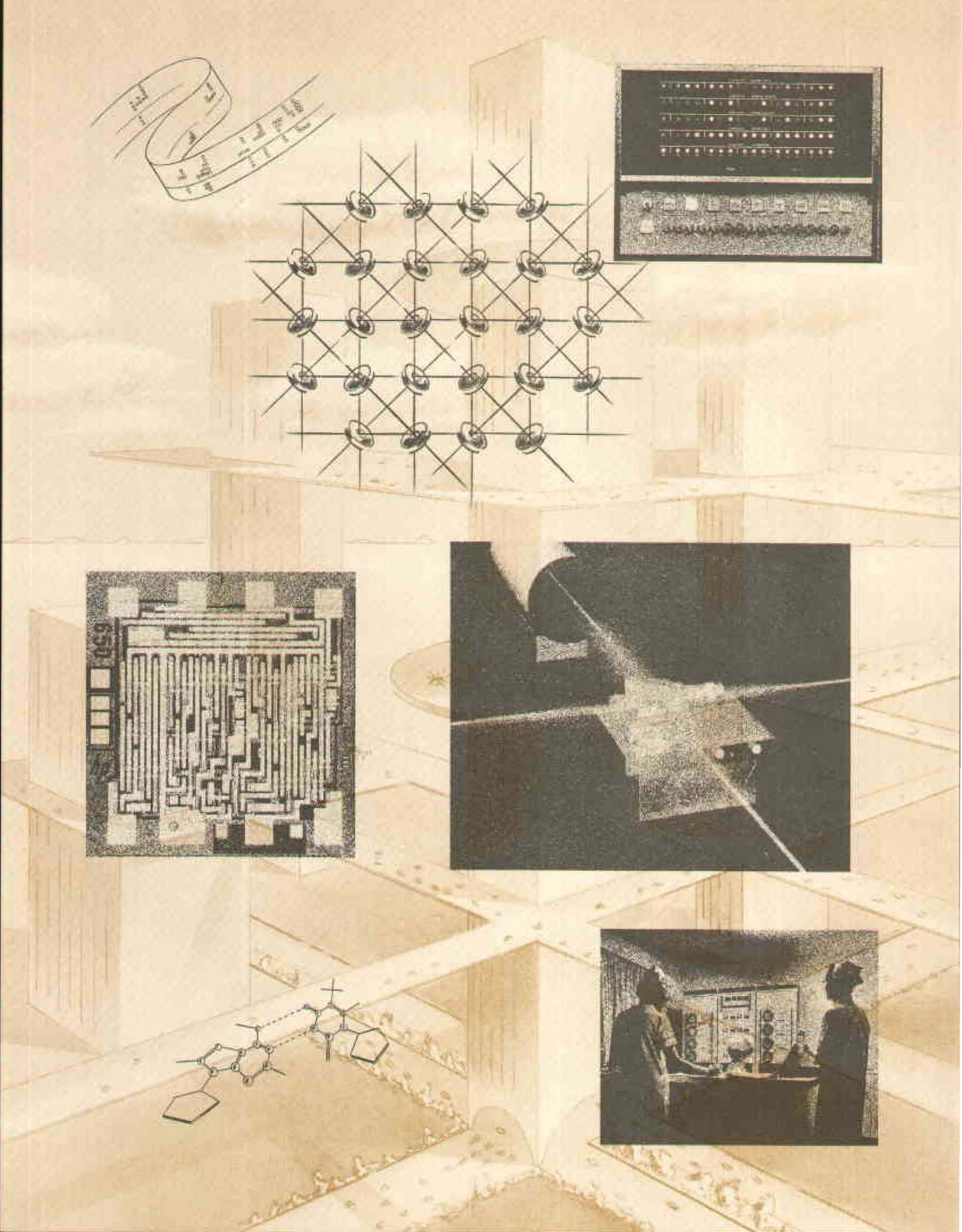
Only if there is precise agreement on the meaning of terms can there be understanding. So first there must be agreement on definitions. This is the primary purpose of the system of measurement standards administered by The National Bureau of Standards and sanctioned by international agreements. Four basic standards — mass, length, time, temperature — are recognized.

From these are derived 36 other standards. Among the 36, 21 of these basic quantities are measured by Hewlett-Packard instruments. Each instrument's readings are traceable to the NBS. The 21 are: x-ray and gamma ray exposure, phase shift, magnetizing force, electric field strength, electron beam current, time interval, energy (electrical), displacement, reflection coefficient, noise (electrical), inductance, electric resistance, velocity, angle, power (electrical), magnetic flux density, attenuation (electrical), electric capacitance, force, acceleration, and voltage.

The immortals of measurement

Through their contributions in identifying and defining measures which are now classic in their fields, a number of people have also gained at least a measure of immortality for their names:

Ampère	A measure of electric current
Ångström	A unit of electromagnetic wave length
Bell (bel, decibel)	A ratio of powers
Celsius (C.)	A scale of temperature measurements
Coulomb	A unit of electric charge
Curie	A measure of radioactive disintegration rate
Fahrenheit	A scale of temperature measurements
Faraday (farad)	A unit of electrical capacitance
Fermi	A unit of distance in atomic measurement
Galileo (gal)	A unit of acceleration of gravity
Gauss	A unit of magnetic field intensity
Gilbert	A unit of magnetomotive force
Henry	A unit of electrical inductance
Hertz	A unit of frequency
Joule	A unit of work, equal to one watt-second
Kelvin	A scale of temperature measurements
Mach	A ratio of velocities
Maxwell	A unit of magnetic flux
Newton	A unit of force
Ohm	A unit of electrical resistance
Roentgen	A measure of x-ray or gamma radiation
Volta (volt)	A unit of electric potential
Watt	A unit of power
Weber	A unit of magnetic flux



ELECTRONICS AND THE FLASH GORDON SYNDROME

Is your heart set on ownership of a robot slave? Do you have ambitions of retiring to a hydroponic farm in the Mindoro Deep? Is Alpha Centauri a way point in your dreams of celestial navigation? Or would you settle for a life of programmed pleasure here in Megalopolis III?

Electronic engineers stoutly, and rightly, refuse to talk in these terms about the future, even though a few of their number have been known to contribute to science fiction. When thinking about their future they consider it in the light of the logically possible, based on what is known now.

Since instruments set the limits to what can be understood, for the instrument maker there continues to be a challenge in attaining "outer limits" capability in measuring the speed and depth of events.

Some startling advances have been made in this direction recently to allow measurement of quantities that were previously out of range. Electrical signals of less than one-millionth of a volt can now be detected in the presence of many volts of interference. Time intervals as small as 100-trillionths of a second are also measurable; conversely, larger units of time can be read with an accuracy comparable to measuring the distance from earth to sun with less than a one-inch error. Oscilloscopes now can show wave forms at frequencies beyond 12.4 billion cycles per second. Pesticide residue concentrations expressed as parts per billion can be found in food products by gas chromatography.

Interestingly, such measurements can be readily accomplished in ordinary lab environments with off-the-shelf equipment.

But pressing the limits of measurability is not the industry's most significant trend. That trend arises in the need by the scientist, physician, or engineer for a faster, more complete and more meaningful view of his subject.

Until recently, attaining that view has been a laborious chore. Whether the view desired is the condition of a heart attack patient or the design of a machine, the measurement has been but a prelude. The information provided by the instrument has to be translated into medical or engineering terms. Many other observations and calculations must follow. Finally, after much effort by professional or technical personnel, meaning may emerge.

One HP response to this need has been to develop instruments which are more complex internally but easier to use and more general in application. As a simple example, some new instruments have fewer knobs. At a more complicated level, instruments carefully designed to be compatible can be easily combined to solve complex measuring problems. Charts may be provided, with which the technician can interpret results immediately in the form he desires. More sophisticated are new programmable instruments, such as the HP programmable oscilloscope. It can be switched automatically from one kind of observation to another, either with a button or with automatic programmers.

There is also the challenge of measuring in new and difficult environments. In medicine, for example, instruments now can sense delicate fluctuations in the life processes of a heart attack victim. By monitoring this information continually, such an intensive care system can be used to forecast and prevent further suffering. Thousands of lives are thus saved each year now.

But beyond sophisticated automatic instrumentation lies the impact of the computer. Already it is becoming the "master instrument" in a measurement revolution.

This future is already apparent in the small instrumentation computer HP introduced in late 1966. Unlike other computers, it readily "interfaces" with measuring instruments. Without requiring the usual months of time to work out computer-instrument intercommunications, it can quickly be connected to control the measuring process, and to interpret the results. The answers can come out directly in the language of the engineer, chemist, or physician.

Such a computer can be programmed with stored data to correct the information it causes to be collected, as well as to make decisions about the information, causing appropriate further tests to be made.

The engineer, for example, will be able rapidly to explore aspects of his design or process which time would never before permit. With stored programs, worked out by others with similar problems before, he can virtually use their brains to solve his problems.

The medical researcher and the physician will more and more be able to "talk" to a sophisticated instrumentation system, without acquiring engineering know-how.

Commenting on the introduction of the instrumentation computer, Barney Oliver, HP's vice president of research and development, notes that "though we say we are in the electronic measurement field, really and somewhat more broadly speaking, we have been in the business of gathering data electronically.

"Now we are rapidly getting into the business of automating that task of data gathering and further, of processing those data. Incorporated with our other instruments, the low-cost, small-scale computer will create a new era in measurement, greatly simplifying yesterday's tasks, and making electronic measurement valuable in other new fields."

The oceans, pollution control, transport systems, systems of weather monitoring and control, and the task of feeding the world's hungry peoples all pose challenges which can only be met by taking an infinitude of measurements and interpreting them meaningfully.

New standards of measurement are in the making. A new method of establishing the absolute ohm was introduced recently. The cesium-beam clock, which keeps time to within a second each 30,000 years, has been adopted as the official timepiece for a system to keep track of orbiting satellites and alert us to the flight of missiles. The laser gives promise of providing an even more precise definition of the meter than the krypton-86 standard adopted in 1960.

Just over 2,300 years ago, Protagoras delivered his historic saying: "Man is the measure of all things." Had he envisioned today's world he might also have said that man is the *measurer* of all things.

Measured day of the typical man

How much do you measure? And how much do you rely on measuring devices to get you through the day? Let's see what happens to Mr. and Mrs. Tom Typical:

The alarm on the clock radio starts their morning. Mrs. Typical switches the electric blanket off.

In the kitchen the stove performs a variety of measurements, all controlled with buttons and dials. The electric coffee pot stops perking at a preset temperature. The wall clock now tells Mr. Typical to be on his way to work.

The car he drives is a bonanza of measuring devices — from automatic choke to fuel level to automatic transmission to speed and mileage gauges. He passes safely through a radar speed gauge. Centrally synchronized traffic lights usher him down the expressway. At the garage, he asks the attendant to fill the tank, and also check the tire pressure, the oil and water levels. At his place of work, an electric eye notes his approach and signals to the elevator door that Mr. Typical has arrived. He pushes the floor button, enters his office, turns on the air conditioning, and then begins dictating into a machine which automatically measures his voice volume and adjusts to its level.

Meanwhile, Mrs. Typical is busy measuring an amount of laundry detergent, knowing that a proper setting of the dials will take care of measuring the water, the temperature, and the time cycle for washing, rinsing, and spin-drying.

She will have other occasions to use measuring devices during the day. There will be the dryer, the temperature-controlled steam iron and the dishwasher. At the market, some of her purchases are weighed. In all the rush to finish her chores before her husband returns, she almost forgot dessert. Fortunately, there was still a package of pre-measured pie mix in the cupboard.

And after he had been home a short while, Mr. Typical raised a question about another measuring device. "Honey," he said, "where's the shot glass?"