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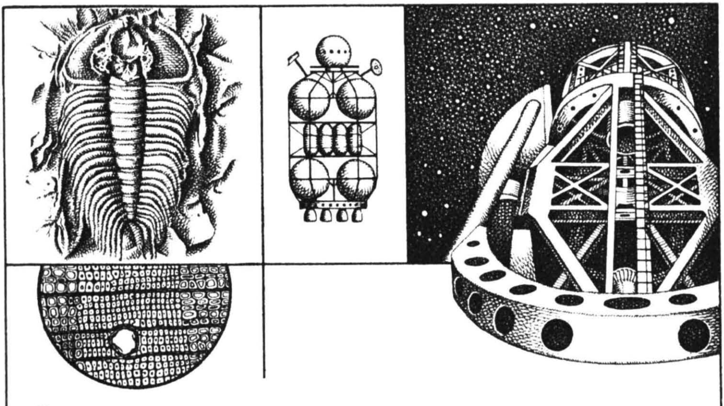
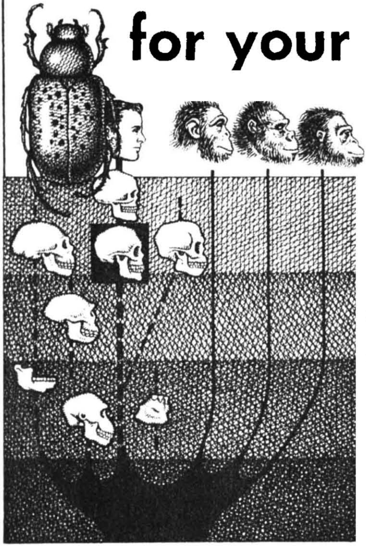


for your information

By **WILLY LEY**



DEATH OF THE SUN (II)

CONTEMPLATING the activities of and on the Sun must have been very frustrating to 19th century astronomers. It was well known that everything on Earth, from major weather events to the growing of a blade of grass, depended on light and heat from the Sun. It was also known that the planet Earth intercepted only a tiny portion of the light and heat generated.

Since the astronomers of the 19th century knew that everything on Earth depended on the Sun, the question of how the Sun kept going—and whether it might one day fail—was not merely a point of scientific curiosity; it acquired a very personal aspect. If you read through a pile of old astronomy books, you can easily see how frustrating the whole thing was.

THERE was, as explained last month, the so-called meteoritic theory. If meteorites amounting to one Earth mass per century fell into the Sun, their impact energy ought to be enough to account for the energy generation. One Earth mass per century, on the other hand, was so little in comparison with the enormous bulk of the Sun that the increase in diameter would be virtually negligible. It would take centuries to detect it even after you knew what you were looking for.

But unfortunately you could not expect all the meteorites to fall into the Sun in a straight-line fall. They would approach the Sun in a tight spiral, which meant that if the total of one Earth mass per century was to fall into the Sun, several Earth masses should move around it close to its surface. And that would be enough to be easily visible, perhaps even to the naked eye. Hence meteorite impact could supply only a very small amount of the total energy generation; it could only be incidental to the main process.

Then there was Helmholtz's contraction theory. You did not have to have meteorites fall into the Sun; you could get the same result by having particles from the outer layers drop down to lower layers. The overall result of this would be a gradual contraction of the Sun, but Helmholtz had shown that this, too, would be so little that it would take centuries to measure it.

One drawback was that there had to be an end to the process; it meant that the Sun would finish its career as a star some eight to ten million years in the future. That did not constitute disproof in itself, of course. If the Sun was to cease shining eight or ten million years in the future, this was simply an inevitable fact and, in spite of all its inevitability, it wasn't something to worry about: measured by human standards, eight million years is a very long time.

The real drawback was at the other hand of the time scale. Calculating backward by the same method, you could tell when the Sun had started shining—and that was far too short a time. The Earth (even before radioactivity measurements were discovered) must be older than that and a number of courageous zoologists and paleontologists stated boldly that life on Earth should be older.

Having disproved one of the two possible explanations themselves, and seeing the other disputed by the geologists, astronomers had no way to turn.

One of them wrote in desperation: "If we could only tell how much of the Sun is liquid, how much is solid and how much is gaseous, we might be able to find an answer!" We now know that nothing could be solid or even liquid on an 864,000-mile sphere with a surface temperature of 6000° centigrade and a core temperature of 20 million degrees centigrade, but at that time the statement was perfectly logical.

Another astronomer more courageously summed up that the energy generation of the Sun was either due to a combination of contraction and meteorites, "or else to a process of which we have no idea or concept at the present time."

OF course, that was the truth. At the moment those lines were written, the atom was still believed to live up to its name (Greek *atomos* means "indivisible") and no one thought that there might be energy in the atoms, even if they should turn out not to be indivisible. Science was more or less stuck with Helmholtz's contraction theory of 1854, when one could easily make the assumption that in the past, meteorite falls had supplied much more energy than they do now, so that a longer period of sunshine became available for the past, at a time when there were no astronomical observers.

That the atom was not strictly indivisible and that energy was released by this very fact became known during the decade from 1896-1906. Some ten years after that, Sir Arthur Eddington began his theoretical work on stellar interiors. At almost every point of his thinking, lack of knowledge of atomic behavior interfered and he finally exclaimed that he had intended to delve into the interior of the stars and ended up in the interior of the atom. But this apparently irrelevant detour actually cleared up the question.

We must keep in mind at this point that up to the year 1919, it was believed that radioactivity could not be influenced in any way. It had been found in the laboratory that certain heavy elements — uranium, polonium, thorium and radium — did "decay" into something else, releasing energy in the process. But the decay rate seemed to be given and fixed. It remained the same in the coldest cold chamber that could be produced. It did not change with heat. It remained uninfluenced by electric currents or magnetic fields.

In 1919, Ernest Rutherford succeeded in smashing a nitrogen atom. This opened entirely new vistas. One had not been able to influence radioactivity by heat or by electric currents. Maybe it merely had not been hot enough or the current had not been powerful enough.

Ten years after Rutherford, two young scientists, Robert Atkinson and Fritz Houtermans, dared to say for the first time that the nucleus of an atom might be attacked if it was hot enough. As is now known, the kinetic energy of a bit of matter increases with heat. The hotter it is, the faster it will move and the energy, naturally, depends on the speed.

When Atkinson and Houtermans made their statement, it was a comparatively recent item of knowledge that under conditions of extreme heat, something else will happen to atoms. Normally, which in this case means any temperature from room temperature to that of molten steel and beyond, each atomic nucleus is surrounded by its swirl of electrons.

Simplifying things a bit, it was assumed that these electrons had a kind of cushioning effect. If, at "normal" temperatures, one atom bumped into another, they bounced off their electron shells, the nuclei remaining unaffected. But as the temperature went up, the electrons were gradually "stripped" from the nucleus; at very high temperatures, the nucleus of the atoms would be bare. At the same time, the speed with which they moved was increased by the temperature, too. Then, in a stellar interior, you had "naked nuclei" racing about at colossal speeds.

Under these conditions, it seemed possible—even probable—that the nuclei might be affected by collisions. But that was as far as one could go in 1929—the general statement that "thermonuclear reactions" *should* be possible was all that could be said. One could not yet be specific.

IF you read popular articles on atomic energy nowadays, you can easily get the impression that it all began with the accidental discovery of the fission of uranium by Hahn and Strassman. And that, after this discovery had been verified and the fission bomb had been built and used, scientists began to wonder about the fusion of light atoms and finally contrived the hydrogen bomb.

Now this may be a nice and simple scheme for explaining things to an outsider, but it is not correct historically. Even before it was known that heavy elements like uranium could go into fission, scientists were talking about generating atomic energy by fusion. Not that they talked about doing it themselves; they talked about it as something that probably went on inside the stars.

One likely reaction seemed to be the fusion of a lithium nucleus and a hydrogen nucleus into a helium nucleus. But that could not be what happened in our sun. It would be far too fast under the circumstances actually prevailing. It would result in one big flash and that couldn't be it. As George Gamow wrote then, "We know, therefore, that our sun cannot contain any appreciable amount of lithium in its interior, just as we know that a slowly burning barrel surely cannot contain any gunpowder."

What really keeps the Sun going was figured out for the first time under somewhat unusual circumstances. In 1938, a Conference on Theoretical Physics took place in Washington, D. C., and one of the participants was Dr. Hans Bethe of Cornell. As he was riding home on the train, he decided that one should be able to find the proper reaction by checking through a number of possibilities. It seemed likely that the energy output of different nuclear reactions should differ greatly in magnitude so that, if one could find a nuclear reaction which tallied with the actual energy release of the Sun, one could be fairly sure of having the right one.

Professor Bethe started checking through a number of likely nuclear reactions. Before his train pulled in, he found one which gave the right result!

Strangely enough, Dr. Bethe's colleague, Karl von Weizsäcker in Germany, arrived at the same result (I don't know under what external circumstances) at the same time. The cycle of reactions is usually called the "Solar Phoenix Reaction" because the carbon atom which is involved reappears unchanged at the end, so that it acts more like a nuclear catalyst.

Naturally, in such a self-consuming cauldron as the Sun, with the enormous size and the temperatures involved, more than one nuclear reaction will go on. A little over 10 per cent of the total energy generation is thought to be due to what has been called Critchfield's H-H process which assumed a head-on collision of two protons (hydrogen nuclei) with subsequent ejection of a positron. A third reaction that probably happens is this one.

As has been intimated, the

(TABLE 1)
THE SOLAR PHOENIX REACTION

Step No.	*Reaction*	*Time Constant for Center of Sun*
(1)	${}_1\mathrm{H}^1 + {}_6\mathrm{C}^{12} \rightarrow {}_7\mathrm{N}^{13}$	40,000 years
(2)	${}_7\mathrm{N}^{13} \rightarrow {}_6\mathrm{C}^{13}$ + positron	10 minutes
(3)	${}_6\mathrm{C}^{13} + {}_1\mathrm{H}^1 \rightarrow {}_7\mathrm{N}^{14}$	7,000 years
(4)	${}_7\mathrm{N}^{14} + {}_1\mathrm{H}^1 \rightarrow {}_8\mathrm{O}^{15}$	1 million years
(5)	${}_8\mathrm{O}^{15} \rightarrow {}_7\mathrm{N}^{15}$ + positron	2 minutes
(6)	${}_7\mathrm{N}^{15} + {}_1\mathrm{H}^1 \rightarrow {}_6\mathrm{C}^{12} + {}_2\mathrm{He}^4$	20 years

Net result: $4\,{}_1\mathrm{H}^1 \rightarrow {}_2\mathrm{He}^4$ + 2 positrons

various thermonuclear reactions depend on temperature. Obviously they cannot be the same for every star; some stars are hotter than our sun and some are cooler. In a star like Sirius—hotter but otherwise of the same general type—there can be very little of the H-H process, while this process might be the sole or at least main energy source in a fainter star.

Knowing now that thermonuclear reactions — fusions of light atoms — provide the energy of the stars and knowing, too, at what temperature the various reactions can take place, we can search an entirely new picture of stellar evolution.

You remember what they thought of stellar evolution before atomic energy was known. In the beginning, they put an uncondensed star—the term now in use for this is "proto-star"—which by way of contraction was finally hot enough to shine with visible light. As contraction progressed, the star went through a

(TABLE II)
POSSIBLY "COMPETING" REACTION

Step No.	*Reaction*	*Time Constant for Center of Sun*
(1)	${}_1\mathrm{H}^1 + {}_1\mathrm{H}^1 \rightarrow {}_1\mathrm{H}^2$ + positron	10^{11} years
(2)	${}_1\mathrm{H}^2 + {}_1\mathrm{H}^1 \rightarrow {}_2\mathrm{He}^3$	2 seconds
(3)	${}_2\mathrm{He}^3 + {}_2\mathrm{He}^4 \rightarrow {}_4\mathrm{Be}^7$	30 million years
(4)	${}_4\mathrm{Be}^7$ + electron $\rightarrow {}_3\mathrm{Li}^7$	1 year
(5)	${}_3\mathrm{Li}^7 + {}_1\mathrm{H}^1 \rightarrow 2\,{}_2\mathrm{He}^4$	1 minute

Net result: $4\,{}_1\mathrm{H}^1$ + 1 electron $\rightarrow {}_2\mathrm{He}^4$ + 1 positron white phase (Sirius as an example) then through a yellow phase (our sun as an example) and finally, when most of the energy had been radiated away but contraction was virtually finished, the red phase. The black and invisible phase was to be the end.

The modern concept still begins with the proto-star, a fantastically tenuous accumulation of gas molecules with some cosmic dust mixed in; that dust later evaporates into gases when the temperature rises. And early in the career of a star, old Helmholtz's contraction theory actually applies to the full.

The heat generated is produced by contraction and, as the process goes on, the star grows hotter, producing more heat by contraction than is radiated away from its steadily shrinking surface. Therefore the temperature in the core approaches a point, after a while, where thermonuclear reactions will start. At that time the star is still enormous as far as volume occupied is concerned, but is still very tenuous and not very luminous. It is a so-called Red Giant.

TAKING a specific Red Giant, epsilon Aurigae, it can be demonstrated that the temperature of its core is not yet high enough to keep a reaction of the type of the Solar Phoenix cycle going. The reaction must be between deuterium and hydrogen (or heavy hydrogen and ordinary hydrogen), resulting in helium and energy.

It is an interesting point that the star's mass acts as a kind of safety valve. Supposing the nuclear reaction was too violent, the heat produced would simply expand the whole star. That way, the radiating surface increases and, in an extreme case, the core may simply grow too cool to sustain the nuclear reaction. Then the star would rely on contraction until the core grows hot enough again.

Astronomers know a number of stars which bear the designation of "pulsating stars." They expand and shrink at regular intervals. It is thought—but, as far as I know, not yet completely proved — that these pulsating stars are forever on the borderline between Helmholtz's contraction and thermonuclear energy generation.

Every time they have contracted enough to heat their interior to nuclear activity, the nuclear activity grows violent enough to expand the whole star and quench the nuclear fire. Just what conditions are necessary to put a star into this dilemma is not yet known. Obviously the majority of the stars somehow escaped this difficulty and went on to higher core temperatures. Some known Red Giants must rely on the lithium-hydrogen reaction mentioned earlier. Still hotter ones rely on a reaction converting boron and hydrogen into helium.

You must have noticed that these thermonuclear reactions which keep the stars going always end up with helium. Since the reactions must start at the very core, where it is hottest, one can assume that helium will accumulate at the core, finally to the virtual exclusion of all other atoms. Logically then, as a star grows older, the reaction no longer takes place at the precise core. That is taken up by the atomic slag heap of helium atoms.

We have to picture, in that case, a core of no longer reacting helium, of uniform and very high temperature. The "surface" of this central helium sphere is where the thermonuclear reactions take place. The area above the reacting spherical shell is still too cool to let reactions take place. As this reacting sphere grows, the rate of conversion of other elements into helium grows, too. Hence as a star uses up its fuel faster, the less is left of it.

Percentagewise, Sirius "burns up" more hydrogen atoms than the Sun every second. It is, from this point of view, an "older star" while our sun is still so young that its end lies not several million but several billion years in the future.

AT some time near the end of the star's life, something happens. Possibly the generating shell comes so close to the surface that all the nuclear fuel above it is consumed in a flash. After that, the star collapses to form one of the super-dense White Dwarfs. Since a White Dwarf has absolutely no method of energy generation left—it has used up all the elements which could be nucuear fuel and cannot contract any more—it must be considered "dead."

As a side-issue, I would like to mention a recent idea about the Blue-white Giants. Fred Hoyle in England has made much of the idea of stars passing through clouds of cosmic dust and acquiring large amounts of matter by "tunneling" through such a dust cloud, a variation of the old meteoric impact theory. Such an event must be rare, but astrophysicists feel that the rare Blue-white Giants fit this assumption. They are, then, not stars in a certain (and somewhat mysterious) state of stellar evolution, but "rejuvenated stars" which might have held any place in stellar evolution before they entered a cloud.

How about the "black stars,"

though, which were so much discussed a century ago? The overwhelming probability is that there aren't any. As long as there is *any* method of energy generation left, the star will utilize it. And when it has finally reached the ultimate stage of the White Dwarf, it combines an enormous heat content with a very small radiating surface, since a collapsed star probably has about the same diameter as the Earth.

Figuring things very carefully, a White Dwarf should need some 8,000 million years to radiate away its energy and turn dark.

But the Universe is probably only half as old as that figure—so that even the very first White Dwarf ever to form must still be luminous!

The question "When will the Sun die?" is, in terms of that fact, just about as academic as any could be. If it's keeping you up nights, you have about 4,000 million years — minimum! — to stay awake worrying, so let's put out the light and go to sleep, shall we?

ANY QUESTIONS?

Just what does "terminal velocity" mean? I had always thought that a body falls faster and faster the longer it falls. But from something I've just read, it seems that this is not always true. What is the answer?

Eva Sidera
7221 Sunset Boulevard
Hollywood, Calif.

Looking at falling bodies from the point of view of a man (or woman) on the ground, it is almost never true that they fall the faster the longer they fall. The reason is air resistance. Let's take a specific example. An airplane sheds a wingtip fuel tank at a height of three miles. According to one of the so-called Galilean equations, the tank's impact velocity on the ground will be $v = gt$, which simply means that at the end of every elapsed second, it falls 32 feet per sec. faster than at the beginning of the same second.

If the empty fuel tank had been jettisoned by a rocket three miles above the Moon, the formula would actually hold true. Of course you'd have to use the "g" that applies to the Moon, not the one that applies to the Earth.

But on Earth, we have air resistance. As the tank begins to fall faster and faster, air resistance grows stronger and stronger. The important factor is that air resistance grows much faster. Soon, therefore, the point is reached where air resistance prevents any additional increase in falling speed.

From then on, the body will fall with a virtually uniform velocity, which is the "terminal velocity." For a fall from a very great height, like a long-range missile falling out of the stratosphere, terminal velocity will never be established; the impact will take place before a balance could be achieved.

As for figures: the terminal velocity of such an empty wingtip tank might be around 100 mph. If the tank were jettisoned full, with all the fuel in it, the terminal velocity would be somewhere around 300 mph and that of a bomb, with thick steel casing and packed with high-explosive, around 900 mph. It is for this reason that there have been bombs with a rocket charge to push them downward faster. On the other hand, if you wish to decrease terminal velocity, just add something with lots of air-resistance—a parachute, for instance.

In many stories—in fact, almost all of them—while the rocket is under power, there is an increased gravity. I know that while rising from some gravitational source, such as a planet, gravity and weight would seem to increase. Beyond a certain distance from a gravity source, gravity is said to be almost nil. In the books, while the rocket is in free fall, there is no weight. Okay. But when the rocket is moving, there is weight. And as soon as the power cuts out, there is no weight, even though the rocket maintains the same velocity.

Will you please explain why such artificial weight occurs under power? I would very much like to know.

Buddie Akers
(no address given)

I have answered a very similar question once before, but a repeat might do some good, for I know that many people are confused on these points. The confusion, it appears to me, is based on two misunderstandings. Misunderstanding No. One is that the nearness of a large and heavy body (a "gravitational source," to paraphrase Mr. Akers) must produce "weight" no matter what the circumstances. Misunderstanding No. Two is apparently that *only* a "gravitational source" can produce "weight." In reality, things are quite different.

A gravitational field will influence the movement of a nearby body, deflect it from its course or make it fall. But it will not produce the feeling of "weight." That sensation is caused by resisting the pull of the gravitational field.

As I am sitting here typing, I am supported by my chair, the chair is supported by the floor and the floor by the house and ultimately by the ground. This support prevents me from following the gravitational pull and this fact causes the sensation of weight. If I could fall freely into a deep well under my chair, I might come to a bad end, but I would *not* feel weight while the falling lasts.

The increase of weight in a rising rocket is due to two factors: as long as it stands on the ground, things are the same as if it were a house. When it begins to rise, the acceleration even goes the other way. The pull of the Earth is not just passively resisted but overcome by brute force into faster and faster movement against the pull of gravity.

This brings us to Misunderstanding No. Two. If a body like a spaceship is freely floating in space, leisurely following some weak gravitational pull from somewhere, there is "zero g" in the cabin—complete absence of weight, no resistance to movement. But when the rocket motors start up, accelerating the ship, they enforce a new movement. The force applied meets with resistance (the inertia of the things inside the ship and also that of the ship itself) and hence weight appears.

When the rocket motors are shut off again, the ship will move with a different course, but then nothing will counteract the gravitational forces which may be playing on the ship and nothing will disturb inertia—again no weight.

Another point that enters here is that our body has no organ for detecting its own velocity. It cannot "feel" velocity; it can only note changes in velocity, acceleration or deceleration.

In short, the feeling of weight can be caused either by accelerating where inertia resists the change, or else by resisting the pull of a gravitational field.

What would a man's weight be at the exact center of the Earth? According to one formula, the answer should be infinity; however, since the forces are theoretically equal on each side, the weight should be zero. What is your opinion?

Henry Oden
2317 *Myrtle Street*
Alexandria, La.

This is not a matter of opinion. The second answer is correct. In the precise center of the Earth (or any other planet, for that matter) equal masses would act from every direction on the body in the center. Since they would all cancel out, the result would obviously have to be zero. The formula you have in mind applies only to attraction from *one* direction.

I just reread your column on Mars in the July 1954 GALAXY *and wonder whether there are astronomical works specifically about that planet. I have a reading knowledge of French, in case this should help.*

Chester P. Talley
16-36, 62*nd Street*
Maspeth, L.I. N.Y.

A reading knowledge of French certainly helps in this case because the most recent comprehensive book on Mars happens to be in that language. Its title is *Physique de la Planète Mars*, written by Gérard de Vaucouleurs. A shorter book by the same author exists in English under the title *The Planet Mars*. Both were published in 1950.

Most recent in this country is *The Red and Green Planet* by Hubertus Strughold, M.D., Ph.D. (1954), unless a scheduled book on Mars by Dr. Robert S. Richardson has been published by the time this column appears in print. Of interest are *Observations of Mars and Its Canals* (1941) and *Observations of the Planet Mars* (1936), both by Harold B. Webb.

And in case you have a reading knowledge of German, too, I recommend for a quick survey *Mars, seine Raetsel und seine Geschichte* by Robert Henseling (1925).

What is known about the physiological effects of high acceleration? In particular, how much can the body stand momentarily and continuously?

Millard H. Perstein
1447 *Willard Street*
San Francisco 17, *Calif.*

Many acceleration tests have been carried out by means of centrifuges and it is now known that an acceleration of 3 g for ten minutes can be borne without aftereffects. (That would have been more than enough to produce escape velocity, if it had been a straight line acceleration.)

As for higher g forces: one volunteer endured 17 g for one minute without detectable harm and others have endured as much as 30 g for a number of seconds.

As regards the acceleration human beings can stand, especially when lying almost flat on their backs, it is no deterrent to space travel.

—WILLY LEY