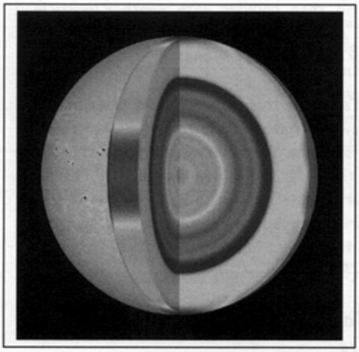
How old is Sunlight?



How long does it take for light to get out from the center of the Sun?

Most textbooks say that it takes light between 100,000 and 50 million years to escape. You would be surprised to know that this simple, and very popular question, seems to be without a firm answer. Most astronomical quantities are, after all, known to far better accuracy.

The table below shows some examples of the value of this number for a number of textbooks and articles about the sun. In science, most numbers that represent physical quantities get more and more accurate as time goes on. Plot the estimates in the table and see if the light travel time value is improving with time.

Year	Estimate
1964	1,000,000
1973	2,000
1977	10,000,000
1980	50,000,000
1981	1,000,000
1982	10,000,000
1984	1,000
1990	10,000,000
1991	1,000,000
1996	10,000,000
1999	1,000,000
2000	300,000
2001	10,000,000
2002	30,000
2002	170,000
2003	1,000,000
2004	17,000
2004	50,000,000
2004	4,000

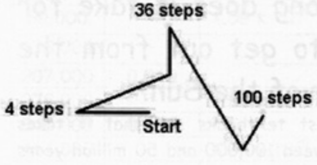
If you plot the common estimates for the travel time that have appeared in print since 1964, it doesn't look like the number is improving with accuracy as time goes on. One author quotes an earlier author's estimate and leaves it at that. If dozens of textbooks can't agree to quote a single consistent number, it makes it look like astronomers are being sloppy in describing what should be a fundamental property of the nearest star to Earth.

Why are there so many different estimates?

Astronomers are not particularly interested in the exact value of the number. They only want to make the point that it takes a LONG time for light to escape the sun's core, so they tend not to bother doing the exact, but tedious, calculation. The reason for the huge differences has a lot to do with the assumptions that go in to making the calculation. Each person chooses what they think are reasonable assumptions, and makes an estimate.

On the next page, we will see how to do the calculation a more accurate way!

A Random Walk Through the Sun



A figure showing the progress made after the indicated number of steps

Imagine a particle that travels for a short distance and then collides with another particle. After the collision, it changes its direction in a random way and heads off in another direction.

Let's model this 'random walk' problem and discover how many steps we have to take to reach a particular distance from the starting point. The figure to the left shows one pattern of results. Expect your plotted results to look different! The more experiments you run, the more your averages may follow the 'square-root' law.

Step 1: On a square piece of 3"x3" cardboard, draw a circle and divide it into four quadrants. Label the quadrants: Left, Right, Up, Down. Use this card to make a 'Spinner' like the one used in some board games.

Step 2: On 1 centimeter gridded paper, draw a standard 'X-Y' graph with an origin at the center of the paper.

Step 3: Spin the spinner once. If the pointer lands in the 'UP' quadrant, place a spot 1 cm above your current location and connect it with a line. If you land on 'Right', place a spot 1 cm to the right of your current location and connect it with a line. Do likewise if you land on the other two possibilities.

Step 4: Spin again, and repeat the marking using the current spot as the origin. See the above figure for the sequence of five spins that correspond to the spinner sequence 'Up, Left, Up, Right'

Step 5: After each spin, measure the distance from the origin to the current point and enter it in Table 1. Have several teams of students do this activity and 'average' their tables together to get a better estimate of the distance traveled from the origin as a function of the number of steps taken.

Step 5: Plot the distance traveled in centimeters (Y) as a function of the number of spins (X).

Table 1: Steps and Distances

Steps	Distance from Origin (cm)	
	Example	Now you try!
1	1	
4	2	
9	2.5	
16	1.7	
25	2.3	
36	3.3	
49	2.5	
64	3.3	
81	2.5	
100	4.2	

Result:

Although much more than 100 steps are needed to show the relationship, the average distance (D) you travel from the origin depends on the square root of the number of steps (N) you take, and the average length of each step (L). The equation that represents the distance for a large number of these steps looks like this:

$$D = L\sqrt{N}$$

The answers to exercises in this handout, along with additional resource material, may be found at

http://image.gsfc.nasa.gov/poetry

A Model of the Inside of the Sun

Table 2: A Solar Model

R	T	P	K
0.0	15.0	158	1.0
69,000	12.0	100	1.5
138,000	10.0	40	2.0
207,000	7.0	15	3.5
276,000	5.0	4	4.5
345,000	3.8	1	6.3
414,000	2.5	0.4	8.0
483,000	1.8	0.15	9.5
552,000	1.2	0.35	13.0
621,000	0.5	0.01	20.0

R = distance from the center (kilometers)

T = temperature in millions of degrees C

P = density (gm/cm^3).

K = opacity of the material (cm^2/gm)

Note - 'Opacity' means how much a material obstructs the passage of light through it.

To figure out how many steps light has to take to escape the sun, we first have to know something about what the inside of the sun is like so we can calculate the step distance, L. Over the years, astronomers have developed ever more accurate models of the interior of our sun. Table 2 gives a simplified version of one such model based on data from the 1973 book *The Quiet Sun* written by former Skylab astronaut and astrophysicist Edward Gibson.

1) **Does the sun have the same density throughout its interior?**

2) **At what radius is the opacity highest?**

3) **If you multiply density times opacity, what are the dimensions of the answer?**

So...How long does it really take?

R	P	K	L
0.0	158	1.0	0.00633 cm
69,000	100	1.5	
138,000	40	2.0	
207,000	15	3.5	0.019 cm
276,000	4	4.5	
345,000	1	6.3	0.159 cm
414,000	0.4	8.0	
483,000	0.15	9.5	0.702 cm
552,000	0.35	13.0	
621,000	0.01	20.0	

<u>Step 1:</u> From the data in the table, calculate the values for L, the length of a single step taken by the light beam, by using the formula below. Enter the value in the column for L.

Example: L = 1/(158 x 1) = 0.00633

$$L = \frac{1}{PK}$$

By completing Step 1 you have discovered something really interesting about how light makes its way from the center of the sun to its surface. The distance light travels before it encounters an atom, changes enormously. Near the core where the sun is the most dense, it can travel only 0.006 centimeters – less than the diameter of your hair. By the time it gets to the surface, light travels the width of your hand before hitting an atom.