ENGINEERING AND SCIENCE
May 1960, Volume XXIII, No. 8

Observations on Aging and Death

by Linus Pauling

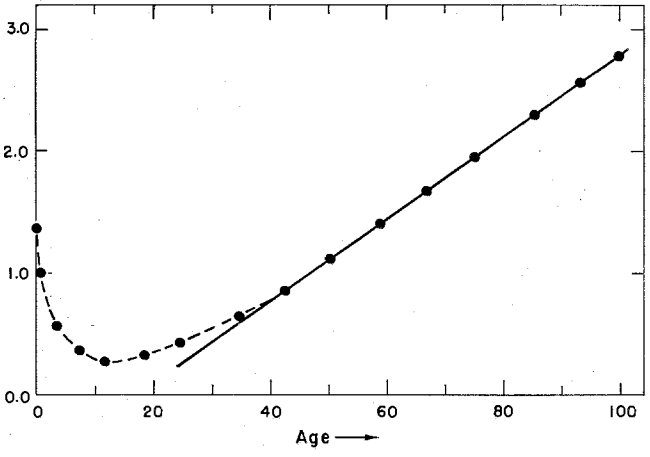
About three years ago we began our research program at Caltech on chemistry in relation to mental disease, with support of a grant from the Ford Foundation. Our attention has been directed largely toward mental deficiency. An important disease that involves mental deficiency is mongolism. One child in six hundred who is born is a mongoloid. Mongoloids are mentally deficient and also show physical stigmata. It has been suggested that they age more rapidly than other people, and we decided to check up on their physiological age, as a possible way of learning something about the nature of their biochemical abnormality. However, when this investigation was carried out (by the late Dr. Richard W. Lippman, medical consultant on our Ford Foundation project, and his co-workers) it was found that there exists no reliable way of measuring the physiological age of an adult human being. The best way seems to be to look at him, and then to say how old he appears to be.

Our work on mongolism was stopped, last year, when the apparent cause of mongolism was discovered. It was found by investigators in England and France that mongoloids have 47 chromosomes per cell, instead of 46. The extra chromosome, which is the small chromosome number 22, probably contains a thousand genes, and, since this chromosome is present three times, instead of twice, as in normal people, the mongoloid probably manufactures a thousand different enzymes in 50 percent greater quantity than normal persons do, and thus has a thousand quantitative biochemical abnormalities. It may well be very difficult to find a treatment for this condition.

Although it is hard to measure the physiological age of an individual human being, it is possible to make some statements about the physiological age of populations. An Englishman named Gompertz discovered, last century, that the age-specific death rates of adults are an exponential function of the age. Infants and children have a rather large mortality, and the mortality reaches a minimum at about age 12 (below). From age about 40 on, the age-specific mortality (the fraction of living persons of that age who die during the year) increases exponentially, with a doubling time of about 8.5 ± 0.5 years. A plot of the logarithm of the age-specific mortality against age is a straight line on the chart below, with slope 0.3 (the log of 2)/8.5 years. The Gompertz relation holds for species of animals other than man, also, and in general the doubling time is about 12 percent of the mean life expectancy.

Professor Hardin Jones of the Donner Laboratory of the University of California in Berkeley has made much use of Gompertz curves in his analyses of factors that affect mortality. Much of the information that I have about this matter has been obtained from him.

Gompertz curves can be plotted for mortality from individual diseases. For example, in the diagram



Gompertz mortality diagram for U.S. residents. The vertical coordinate represents the common logarithm of the age-specific mortality (number of deaths per thousand people of that age), and the horizontal coordinate represents the age. (Diagram by Professor R. M. Sutton).

"Observations on Aging and Death" presents the substance of a Friday Evening Demonstration Lecture given by Professor Pauling on April 8, 1960.

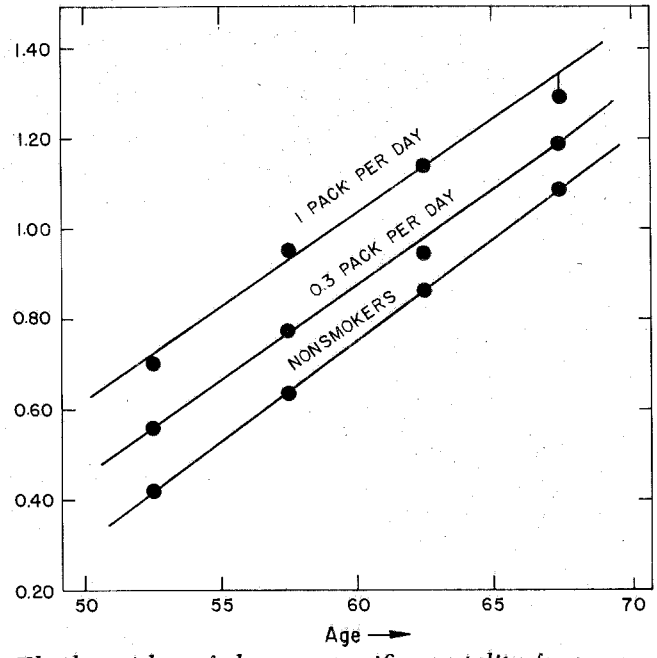
at the right, the Gompertz curves are shown for coronary heart disease; the logarithm of the death rate from coronary heart disease is plotted against age. The values indicated in the diagram are from a statistical study by E. C. Hammond and D. Horn, published in the *Journal of the American Medical Association* 166, 1159 and 1295) in 1958. Closely similar results have been reported by other investigators. The points in the curve represent the average mortality, over five-year periods, for three populations; non-smokers, smokers of 0.1 to 0.5 packs of cigarettes per day, and smokers of about 1 pack per day. For each population the points lie reasonably close to a straight line in the semi-logarithmic diagram. The slopes of the curves correspond to a doubling time of about seven years. The curve for the 1-pack-per-day smokers is shifted by seven years from the curve for non-smokers – that is, the probability that a cigarette smoker will die of coronary heart disease at age 55 is the same as the probability that a non-smoker will die of coronary heart disease at age 62 and is about twice the probability that a non-smoker will die of coronary heart disease at age 55. With respect to this disease, the cigarette smoker behaves as though his physiological age were seven years greater than his chronological age.

Professor Jones has reported that for all diseases the increased mortality of 1-pack-per-day cigarette smokers corresponds to an increase in physiological age of eight years, and that of 2-pack-per-day smokers to sixteen years, relative to non-smokers.

There has been much talk about the increased incidence of lung cancer for cigarette smokers. It has been reported that the incidence of lung cancer for 2-packs-per-day smokers living in the city is 300 times that for non-smokers living in the country. There is a difference in the Gompertz curves for city dwellers and country dwellers, corresponding to a five-year decrease in life expectancy for city dwellers, relative to country dwellers, and part of the decrease in life expectancy may be attributed to an increase in lung cancer, presumably resulting from atmospheric pollution.

Even though the increased incidence of lung cancer among cigarette smokers is very striking, lung cancer is not the principal cause of increased mortality of smokers. R. W. Buechley, R. M. Drake, and L. Breslow, of the California State Department of Public Health, have published a paper on the relationship of amount of cigarette smoking to coronary heart disease mortality rates in men (*Circulation*, 18, 1085 (1958)), in which they have reported results closely similar to those of Hammond and Horn. They also mention that there are four times as many excess deaths associated with cigarette smoking from coronary heart disease as from lung cancer.

As people become older, the incidence of various diseases increases, doubling about every 8.5 years. At my age, when the ills that the flesh is heir to begin to make themselves increasingly evident, one begins



The logarithm of the age-specific mortality from coronary heart disease (deaths per year per thousand persons), as given by Hammond and Horn, from a study of 187,783 men. Values are given for three populations: non-smokers, smokers who average 0.3 packs per day, and smokers who average 1 pack per day.

to appreciate one's youthful period of good health and vigor. As I grow older I must expect to suffer more and more from physical frailty and disease.

One might accordingly ask if it would not be wise to eliminate the period of ill-health and suffering that may be expected to come toward the end of one's life. Would it not be sensible to smoke cigarettes at the rate of 1 pack a day, and die eight years earlier than otherwise, thus cutting off the last eight years of suffering – or even to smoke 2 packs of cigarettes a day, and thus escape the last sixteen years of ill-health and misery of old age? The answer is that this trick will not work. Smoking the cigarettes simply ages you prematurely, shortening the period of health and vigor; the cigarette smoker reaches old age more rapidly than the non-smoker, and only through the turn of the die that might cause an especially early death from lung cancer or coronary heart disease or other disease can he escape the period of failing health.

Analysis of the Gompertz curves for populations in different countries shows some interesting differences. The mortality in the United States is such as to correspond to a mean life expectancy of about 70 years. In other countries the life expectancy is somewhat greater, by three or four years – countries such as Norway, Sweden, Denmark, Holland, and England. It is possible that this difference is the result of a difference in the medical treatment available on the average to people in the United States and in these countries. There are other countries, to be sure, in which the mean life expectancy is less than in the

United States; for example, in Northern Rhodesia it is only 28 years. But the United States still holds the record, for one population: the life expectancy of the Papagos Indians in Arizona is only 17 years.

The nature of the Gompertz relation permits some analysis to be made of the question of the relative importance of various causes of decrease in life expectancy. For example, what would be the result if, through the efforts of investigators in the field of medical research, complete control were to be obtained over cancer, so that no more deaths from cancer would occur?

At the present time cancer causes about 20 percent of deaths in the United States. If cancer were to be eliminated the age-specific mortality would drop to 80 percent of the present value, and the Gompertz curve would be shifted vertically by minus 0.1, the logarithm of 0.8. A shift of 0.3 (the log of 2) corresponds to a horizontal shift of 8.5 years, and accordingly the shift of 0.1 corresponds to a horizontal shift of 8.5/3=2.8 years. Hence the mean life expectancy of Americans would be increased by 2 years and 10 months if complete control over cancer were to be obtained.

Increasing life expectancy

However, cancer is not the principal cause of decrease in life expectancy for Americans. A better effort towards lengthening the average life of Americans could be made by eliminating cigarette smoking. In 1959 Americans smoked 5×10^{11} cigarettes, which is about one-half pack per day for adult Americans. This amount of smoking corresponds to a decrease in life expectancy of four years for the average American. To eliminate cigarette smoking would increase the health and longevity of Americans by 50 percent more than to obtain complete control of cancer.

It may turn out, of course, that it is easier to control cancer than to control cigarette smoking. About 50 percent of adult Americans now smoke cigarettes. From my own observations I conclude that it is to a large extent a matter of chance – environmental circumstances during puberty and early adulthood – that determines whether or not a young man or woman becomes a cigarette smoker. Having become a smoker, however, he finds it hard to stop. The Swiss investigators Hegglin and Keiser have said that "smoking is now the most dangerous drug addiction." Nevertheless, it is possible to stop. Between 1954 and 1959 a marked change occurred in the smoking habits of physicians in Massachusetts; the number of cigarette smokers decreased from 52 percent in 1954 to 39 percent in 1959, with a still greater fractional decrease in the number smoking more than one pack a day.

If both cancer and cigarettes were to be controlled, the life expectancy of Americans would be increased by 6.8 years.

I remember reading a statement some years ago that automobile accidents are the principal cause of decrease in life expectancy for Americans. This statement is not true: cigarettes are five times as important. Neverthless, automobile accidents produce a significant decrease in life expectancy, in part because of the long period of life lost by the victims. About 40,000 Americans per year are killed in automobile accidents. This means that an infant at birth has the chance 1 in 64 of being killed in this way. The average age of death in automobile accidents is 22 years, and accordingly about 50 years is lost for each person killed. The mean decrease in life expectancy for Americans because of automobile accidents is accordingly 50/64=0.8 years.

Professor Hardin Jones has estimated that the effect of high-energy radiation, such as x-radiation, cosmic radiation, and the radiation emitted by radioactive substances, is to cause a shortening of life by 10 days per roentgen of full-body exposure. This estimate permits us to make an estimate of the decrease in life expectancy of Americans due to exposure to background radiation, caused by cosmic rays and natural radioactivity. The background radiation amounts to about 0.1 roentgen per year, which comes to 7 roentgens per lifetime. Accordingly we may conclude that a reasonable estimate of the decrease in life expectancy resulting from exposure to background radiation is 70 days.

The Committee on Genetic Effects of Atomic Radiation of the U. S. National Academy of Sciences-National Research Council reported a few years ago that the average exposure of the reproductive organs of Americans to medical x-rays is about 50 percent greater than the exposure to background radiation. If this figure applies to the body as a whole, then the decreased life expectancy due to medical x-rays can be estimated to be about 100 days.

Effects of high-energy radiation

The exposure of Americans to high-energy radiation from the radioactive fallout of the atomic bombs exploded during the last 15 years has been estimated by various people, including scientists with the Atomic Energy Commission, to be approximately five percent of background radiation. If no more bomb tests are carried out the amount of exposure will begin to decrease after a few years, and the total effect may be approximately five percent of background radiation for one generation of human beings. For these people the decrease in life expectancy would thus be about five percent of 70 days, about 3 days.

A considerable amount of suffering may be caused by the exposure of unborn children to high-energy radiation from various sources. An important report was published a year ago in the British Medical Journal by Drs. Stewart, Webb, and Hewitt. These investigators studied all cases of death by childhood cancer, during the first ten years of life, in England and Wales for the period 1953 to 1955. They found, on

comparison of the histories of the children who had died with those of a control population of children who had not died, that the only factor correlated with death by childhood cancer was exposure of the child to x-radiation before he was born when the mother had an x-ray investigation made of the pelvic region. The average exposure of the fetus was estimated to be 2 roentgen, and the statistical information showed that this exposure doubled the chance that the child would die of cancer during the first ten years of his life – it increased it from 1/1200 for unexposed children to 1/600.

The dangers of air travel

While considering the effect of automobile accidents on life expectancy, I decided to make a somewhat similar calculation about airplane travel. In 1959 there were 0.67 deaths per 100,000,000 passenger miles on American commercial planes, and in 1958 there were 0.34. The average of these is 0.50 per 100,000,000 passenger miles. I am not sure how many passenger miles were flown by Americans, but I believe that it was approximately 3×10^{10}. A simple calculation indicates that travel by commercial airlines is associated with a mortality at the present time such as to lead to about one day decrease in life expectancy for Americans. Moreover, it is found that, per mile traveled, travel by commercial airlines is about five times as safe as travel by automobile.

How much chance of decreasing your life expectancy do you take when you decide to make a trip by air? A jet plane now travels about 500 miles per hour. The number of deaths in commercial air travel leads at once to the conclusion that the decrease in life expectancy resulting from the decision to make the trip by air is about 1 hour per hour traveled. On the other hand, smoking a pack of cigarettes per day for 40 years decreases life expectancy by 8 years; smoking one pack accordingly decreases life expectancy by one fifth of a day, 4.8 hours – which is 14.4 minutes per cigarette smoked. I have measured the length of time required to smoke a cigarette, and have found it to be about 4.8 minutes. Accordingly the process of smoking a cigarette involves a decrease in life expectancy for the smoker which is three times the time required to smoke the cigarette: smoking cigarettes is three times as dangerous as traveling in a jet plane. Traveling in a jet plane while smoking a cigarette is four times as dangerous as traveling in a jet plane and not smoking. If you fly in an airplane and don't smoke cigarettes you are three times as safe as if you stay at home and smoke cigarettes, or four times as safe as if you fly in an airplane and also smoke. I think that this is a very interesting comparison, which all people – all young people especially – ought to know: for whatever length of time they devote to smoking cigarettes they are losing three times that much time from their life.

From our discussion so far, we might reach the conclusion that at the present time cigarette smoking is the principal cause of decrease in life expectancy of Americans. I shall now present an argument indicating that this is wrong – that, instead, it is the existence of stockpiles of nuclear weapons in the world that is the principal cause of decrease of life expectancy of Americans.

The United States has about 100,000 atomic bombs in its stockpile at the present time, and Russia may be estimated to have about 50,000. Of these, I judge that about 20,000 for the U. S. and 10,000 for the U.S.S.R. are in the megaton class. On April 20, 1960 Major General John B. Medaris, in an address before the AFL-CIO Conference on Foreign Affairs, stated that the United States stockpile of great bombs amounts to 30,000 megatons, and we may estimate that if there were to be a nuclear war about 12,000 megatons (80 percent of the Russian stockpile) would be dropped on the United States. The area of the United States is 3,000,000 square miles, so that an attack with 12,000 megatons would correspond to 250 square miles per megaton. The local radioactive fallout from the fission products (with fission assumed to provide 50 percent of the total explosive energy) would be such that during the first day unprotected people in the United States would receive on an average 40 times the amount of radiation needed to cause death by acute radiation sickness. Entirely aside from the blast, fire, and immediate radiation effects, local radioactive fallout from the bombs used in such a great nuclear attack would be expected to cause the death of most of the American people, and an average decrease in life expectancy of about 35 years per person.

War or peace?

This quantity, 35 years, must be multiplied by the probability that there will be a nuclear war. In the absence of reliable information about this probability, I might, as the simplest hypothesis, equate it to the probability that there will not be a nuclear war, and thus evaluate it as one half. Accordingly, the decrease in life expectancy for Americans resulting from the existence of nuclear stockpiles in the world is calculated to be approximately 17.5 years, and thus to be larger than the decrease attributable to any other cause.

I myself believe that there will not be a great nuclear war. I believe that the United States will succeed in its present policy of making international agreements with the U.S.S.R. and other nations so that international control over nuclear weapons is achieved and general disarmament is achieved. I believe that the future will be a future of peace. Nevertheless, we must recognize that the nuclear stockpiles that now exist in the world constitute a great source of danger to all of us.