Issues in cosmology often leave us puzzled because we are not used to think of the universe as a whole, and because of the differences between Newtonian gravity and Einstein's theory of gravity. The concept of the expansion of the universe is one of them. In this excerpt from a lecture by Zeldovich, he explains the basic issues behind the expansion of the universe in his characteristic simple language.

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WHY THE UNIVERSE IS EXPANDING

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"Anyone can invent human beings inside out or worlds like dumbbells or a gravitation that repels. The thing that makes such imaginations interesting is their translation into commonplace terms and a rigid exclusion of other marvels from the story."

(H. G. Wells, *The Time Machine and other Stories*)

WHY IS THE UNIVERSE EXPANDING?

Chemical Explosion and Astrophysical Explosion Similarities and Differences

The expansion of the Universe is a reliably established fact. There was the "Big Bang" about 15 billion years ago. But why did it happen? What are the similarities and differences between the "Big Bang" and ordinary explosions taking place on the Earth?

Let us imagine the charge of an explosive, for example, TNT. It is a compound of carbon, nitrogen, hydrogen, and oxygen. Its energy exceeds the energy of the constituent elements regrouped in another way: as molecules of CO, H_2O, CO_2, H_2, and N_2. The chemical reacion induced by local heating spreads over the entire charge. In a few microseconds the charge is transformed into reaction products – that is, a mixture of gases which has not yet expanded. The pressure of the reaction products at this moment

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is approximately 200,000 atmospheres. The next stage is the expansion of gases, i.e. the actual process known as expansion. The driving force is the pressure difference between the reaction products and the surrounding air. It is the pressure difference which breaks the charge shell and imparts acceleration to the fragments. The reaction products expand, their density decreases and the temperature falls. Consequently, the pressure is also reduced. After the air-borne charge explosion the volume occupied by the reaction products expands until atmospheric pressure is reached inside (for short periods of time the pressure can be even lower than atmospheric); the shock wave travels through the air.

Explosion in a vacuum, in space, results in an infinite expansion. Each fragment and each particle of the reaction products acquire a definite velocity while the pressure acts and then flies further apart, conserving the velocity. The total energy of the explosion is transformed into the kinetic energy of the expanding matter.

I dwell in the picture of an ordinary chemical explosion not only because I have dealt with these explosions for many years but also because comparisons of the explosion of a charge (a process understandable to us in every detail) and the "Big Bang" is very instructive.

Let us begin by noting the similarities. Firstly, an explosion, or, more exactly, the expansion of explosion products, is accompanied by their cooling. Expansion in cosmology is also accompanied by cooling. We mean the hot Universe, bearing in mind that the temperature within the first few seconds reached several billion degrees, thus enabling nuclear reactions to occur. At the same time the present temperature of space is 3K, i.e. minus 270 ^{o}C, which is a very low value. The temperature drop is a natural consequence of expansion.

Secondly, when particles fly apart at constant velocity after a chemical explosion and a period of acceleration, the distance r travelled by each particle is equal, with quite a good accuracy, to the product of the particle velocity u and the time t:

$$r = ut.$$

But this is nothing other than Hubble's law of the expanding Universe. Rewriting the formula as $u = (1/t)r$ and putting $1/t = H$ (Hubble's constant), we obtain $u = Hr$.

So, the two principal similarities of a chemical explosion and the "Big Bang" are: cooling during expansion and the velocity distribution in space.

Does this imply that we have understood the "Big Bang" and that the difference between the "Big Bang" and a chemical explosion is only a quantitative one (I mean the dimensions, pressures and temperatures)? In fact, the charge of an explosive is small in size (from several centimeters to a few meters) while the Universe is very large. The maximum temperature of a chemical reaction is a few thousand degrees, and the density is several grams per cubic centimeter. When speaking about the Universe, we make liberal use of billions of degrees and millions of grams per cubic centimeter. We calculate the processes taking place under these conditions assuming that the earlier conditions were even more extreme.

But the fact to which I would like to draw the reader's attention is, that the main difference between a chemical explosion and the "Big Bang" is qualitative rather than quantitative in nature. Though there is some similarity the causes of the explosions are completely different. One cannot understand cosmology without realizing the difference, and without feeling its depth. So, let us begin to enumerate the differences starting with observation data striking the eye, or, to be more exact, "striking the telescope'' (both optical ones and radiotelescopes).

The first difference expansion after a chemical explosion, does not lead to a uniform volume distribution of matter. First of all, there remains an atmospheric boundary between the reaction products and the air. An explosion in space results in a definite maximum velocity of expansion u_m. There is a vacuum outside the radius $r_m = u_m t$, but within the range $r < r_m$ the density at each instant is different at different points in space similar to the density of different particles of matter.

The density during the "Big Bang" is homogeneous over all space at each instant and there are no boundaries. The constancy of the density (or the uniformity of the Universe, as specialists put it) is confirmed by observations, for example, by far galaxy counts.

The second (and main) difference of the "Big Bang" is that one cannot explain the Hubble expansion of the Universe by pressure differences affecting a particle or on a gas layer.

INITIAL CONDITIONS OF THE "BIG BANG"

The "Big Bang" theory, or, in other words, the theory of the hot Universe, does not explain the expansion. The expansion was initially laid on to the theory. As theoreticians put it, it was laid "by hands", i.e. by an arbitrary prescription of the initial conditions. The answer to the questions "why is the Universe expanding?", and "why are the galaxies flying apart?" is as follows: there was an initial velocity distribution corresponding to the expansion at the very first second (or probably even earlier). The initial conditions should also include a uniform (homogeneous) density distribution in space. In other words, the expansion proceeds by inertia, or to be more exact, the expansion proceeds by inertia in spite of the gravitational drag.

Luckily, according to Hubble's law the expansion changes the density at all points in equal proportion leaving the density a function of time independent of the coordinates. In its turn, the atraction of matter with a homogeneous density reduces the velocity of the relative expansion of any pair of particles, but does not violate Hubble's law, i.e. the relative velocity of each pair of particles is proportional to the observed distance between the particles. The coefficient of proportionality of Hubble's constant depends on time. The term "constant" means that it does not depend either on the direction or on the length of the line connecting the particles.

Such reasons confirm the possibility of obtaining the Universe just as it is observed today of uniform density, and the Hubble distribution of velocities were initially intrinsic in it. Thus, the answer to the question in the title of this article becomes an almost anecdotal antithesis of the famous Chekhov's phrase "it cannot happen because it can never happen". In the "Big Bang" theory we say "It is expanding now because it has always been expanding".

There still remains the question "why is the Universe expanding?" It is thus confined to the question "what caused the required initial velocity distribution in hot plasma?"

As has been established above, high plasma pressure could not create such a velocity distribution. In Newtonian mechanics the force depends on the pressure difference (on the pressure gradient); the same is also true in relativistic mechanics. In the Newtonian Theory of Gravitation the relative acceleration of two particles reduces the velocity with which they fly apart and depends on the density of matter filling the space between the particles. The acceleration formula in the modern Einstein's relativistic theory of gravity (the so-called General Theory of Relativity) includes the sum of the density and tripled pressure divided by c^2 rather than the density itself:

$$\rho + 3p/c^2$$

where c is the velocity of light. The pressure in a plasma is quite high, $p = \rho c^2/3$ and the acceleration doubles ($\rho + 3p/c^2 = 2\rho$) as compared with the acceleration of matter with the same density but without any pressure.

However, though we are talking about the acceleration, its sign is actually negative, since the attraction forces the expansion to slow down. Therefore, the intial velocities of each pair of particles should have been higher than the present ones. The high plasma pressure still amplifies the effect of the slow down in the expansion.

Finally, like in a good detective story we have closely approached the correct answer. Positive pressure does not promote the expansion; therefore, one must have a high negative pressure! If we assume that a definite energy density E_o (corresponding to a matter density $\rho_o = E_o/c^2$) and a negative pressure $p_o = -E_o = -\rho_o c^2$ existed at some very early stage, then the value included in the Einstein gravity equations is negative: $\rho_o + 3p_o/c^2 = -2\rho_o$. From the physical viewpoint it means that gravitational repulsion took place under such conditions, with the gravitational forces creating a universal Hubble expansion from the initial rest. This is the present-day answer to the question in the title.