On Spontaneous Generation

An address delivered by Louis Pasteur at the "Sorbonne Scientific Soirée" of April 7, 1864[1]

Gentlemen!

A number of imposing problems now have our best minds in thrall. These include questions regarding the unity or plurality of the races of Man, whether his creation ought to be dated thousands of years or thousands of centuries past, whether species are fixed, or rather undergo a slow, progressive transformation into new species, how supposedly eternal matter relates to the nothingness outside of it, and whether the idea of God is useless. These are just a few of the issues now subject to learned debate.

You need, however, have no fear that my address tonight has any pretensions toward resolving any one of these earnest questions. But in the neighborhood of such mysteries lies another question, more or less closely related, to which I may, perhaps, venture to direct your attention; for its complexities, which I have made the object of concerted and conscientious study, are accessible to experiment.

This is the question of what we call "spontaneous generations."

Mightn't matter, perhaps, organize itself? Or posed differently, mightn't creatures enter the world without parents, without forebears? This is the question I seek to resolve.

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[1] Revue des cours scientifics, 23 avril 1864, I, 1863-64, pp. 257-264; this text incorporates Pasteur's handwritten corrections. English translation commissioned 1993 by Bruno Latour,

It must be acknowledged that the belief in spontaneous generation has been with us throughout the ages; universally accepted in antiquity, it has become more disputed in modern times, and especially in our own lives. It is this belief I have come to challenge.

The seemingly illimitable perpetuation of this doctrine down the millennia bothers me hardly at all, for as you well know, the most striking errors count their persistence in centuries. But at any rate, should such durability strike you as an argument in favor of the doctrine, I need only cite the evidence once adduced in support of it.

Consider, for example, what the celebrated alchemical physician Van Helmont had to say on the subject, as late as the seventeenth century:[2]

> When water from the purest spring is placed in a flask steeped in leavening fumes, it putrefies, engendering maggots. The fumes which rise from the bottom of a swamp produce frogs, ants, leeches, and vegetation. . .Carve an indentation in a brick, fill it with crushed basil, and cover the brick with another, so that the indentation is completely sealed. Expose the two bricks to sunlight, and you will find that within a few days, fumes from the basil, acting as a leavening agent, will have transformed the vegetable matter into veritable scorpions.

Or take the following passage, bearing in mind that Van Helmont affirms having conducted the experiment described therein (thus furnishing me with my first proof in this lecture that, though it is easy enough to conduct experiments, it is far from easy to conduct irreproachable ones):

> If a soiled shirt is placed in the opening of a vessel containing grains of wheat, the reaction of the leaven in the shirt with fumes from the wheat will, after approximately twenty-one days, transform the wheat into mice.

Van Helmont adds that the resulting mice are adults, male and female, and that they may continue to

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[2] Les oevres de Jean-Baptiste Van Helmont, French trans. Jean Le Conte (Lyon, 1671), Part I, Ch. XVI, "On the Necessity of Leavens in Transformations," pp. 103-109 [My translation --ATL]

reproduce their species by copulation.

Here, gentlemen are experiments of the sort adduced, in the seventeenth century, in favor of the doctrine of spontaneous generation.

Well then, if such absurdities were written on this subject a mere two centuries ago, should we allow ourselves to be moved by the great antiquity of this belief, or by the fame of those who defended it, in their orations or writings, even if their names be Epicurus, Aristotle, or Van Helmont?

On the contrary, when we adopt an historical perspective, it becomes clear that the trajectory of this doctrine follows the pattern typical of false notions. Instead of expanding over time, as only the truth can, it has been steadily shrinking, circumscribing itself ever more narrowly. Today, not a single naturalist believes in the spontaneous generation of insects or mollusks, let alone vertebrates.

But at the end of the seventeenth century, a tremendous discovery, that of the microscope, revealed an entire new world to Man, the world of the infinitesimally small. So while it had, most assuredly, been vanquished as far as the higher creatures were concerned, the doctrine of spontaneous generation now reappeared, audaciously declaring: Here is my province! To be sure, I erred when I thought the relevant conditions could obtain among the higher creatures, but they still obtain among microscopic entities, and it is here we find spontaneous generations. And indeed, strange as it seemed, within a few short hours we saw an infinite number of animalcules appear in the speculum of this new and marvelous instrument, their organization so wondrously simple that it precluded any possibility of sexual generation. These creatures were so numerous, so diverse, and so bizarre, their presence so strongly linked to the presence of dead animal or vegetable matter in the process of decomposition, that we returned to this specious theory, now all the more seductive for having at its service the supple, clever, vibrant, and highly authoritative style of the illustrious naturalist Buffon:

> After death, the matter of living beings preserves a remnant of vitality. Life resides essentially in the body's final molecules. These molecules are arranged as if in a mold,

> where there are as many different molds as there are different creatures. Once death calls a halt to the game of organization, that is, to the holding power of the mold, the body's decomposition ensues. But its organic molecules all survive and, now finding themselves at liberty amidst the dissolution and putrefaction of the body, pass into new bodies as soon as they are captured by the power of some other mold. . . But in the intermission, during which period the mold's power lies dormant, an indefinite number of spontaneous generations may occur. During the interval in which the organic molecules roam freely within the matter of dead, decomposed bodies. . . these organic molecules, always active, rework the putrefied substance, appropriating coarser particles, reuniting them, and fashioning a multitude of small organized bodies. Of these, a few, like earthworms and mushrooms, resemble relatively large animals or vegetables, while the others, almost infinite in number, are visible only under a microscope. All such bodies come about only by spontaneous generation, and they fill the space nature has left between the simple, living, organic molecule on the one hand, and animals and vegetables on the other. This sequence, this chain of being descending from the most highly organized animal to the simple organic molecule, admits of all possible degrees, all imaginable nuances. . .[3]

This, gentlemen, is Buffon's doctrine of spontaneous generation, or, as it is often called in deference to the great naturalist, "Buffon's theory of organic molecules." I will proceed no further without first submitting some of Buffon's supposed spontaneous generations for your consideration. However, I will show you neither earthworms nor mushrooms. As you have just heard, Buffon believed that they entered the world without the help of parents. We no longer share his belief. What I must show you instead are microscopic creatures, because it is to their province that spontaneous generation has been relegated in recent times, to the realm into which, in practice, the light of experience penetrates only with great difficulty. But you may rest assured that, in a little while, it will shine there too, and you will not leave here tonight without being convinced that the spontaneous generation of microscopic creatures is a chimera on a par with Buffon's spontaneous generation of mushrooms and earthworms, or Van Helmont's spontaneous generation of scorpions and mice.

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[3]Buffon, Histoire naturelle de l'homme, Vol. IV (Paris, 1777), Appendix, p. 339. [My translation. --ATL]

Pasteur now has a selection of these alleged spontaneous generations projected on the screen.

To begin with, we have, here, one of the simplest of all vegetable beings: brewer's yeast.

As you see, it is composed of cells, each of which contains a kernel, or nucleus, as the botanists call it. This microscopic vegetation reproduces itself in the following manner:

Each cell extends a little bud, or bulb. This bud grows, and when it has attained the size of the mother cell, detaches itself and, in turn, begins to bud.

Fig. 2 shows vegetation of the same order. Here the budding process may be made out a little more clearly.

Fig. 3 shows the reproductive process common to all molds. Their seeds, or, to use the botanical term reserved for them, spores, are globules like this one. When placed in an hospitable medium, an infusion of organic material capable of supplying them with the nutrients they need, the spores first swell noticeably, then become elongated, projecting tubes of impressive extent. Frequently, in fact, almost always, these tubes branch out, and once their extremities come in contact with air, and are no longer surrounded by fluid, they are crowned, in a variety of ways, with cells like these, that is, with seeds capable of reproducing the species.

I now direct your attention to several animalcules.

When an infusion of organic matter is produced, say, for example, by placing a bit of hay in water, certain of the hay's principles dissolve, furnishing nutrients suitable for the development of microscopic creatures.

The infusoria of hay-water are projected on the screen. These are highly agitated little cells, which rush to and fro.

These tiny creatures are roughly five thousandths of a millimeter in diameter; in other words, if you take a millimeter and divide it into a thousand parts, then take five of these parts, you will have the diameter of one of these globules.

Anguillules [eel-shaped microorganisms] *are displayed next. Their motion, roughly serpentine, is extremely rapid, all the more so because they are in the throes of death-convulsions. They expire after a few moments as a result of the high temperature produced by the microscope lamp.*

Gentlemen, such are a few of those creatures Buffon held to be spontaneously generated, and which are still held so today.

Heated controversies, such as those which arise today among our scientists, are all the more lively, all the more impassioned, for having their counterpart in popular opinion, which, as you know, is always divided between two schools of thought, as old as the hills; these days we call them "materialism" and "spiritualism." What a victory would be won by materialism, gentlemen, if it could cite in its support the demonstrable fact that matter organizes itself, brings itself to life--matter, in which all the known forces of nature may already be said to reside! Do you recall how it appeared in the first of these lectures, in that exhibition of nature's most beautiful phenomena? Do you recall how powerful it is, and how weak, how obedient to the scientist's will? Ah! If we also granted matter this other force we call life, life in all its many manifestations, varying as it does according to the conditions under which it is encountered, what would remain but to deify it? What could then be gained from recourse to the notion of an original creation, to whose mystery we must defer? What use the idea of a divine Creator? But listen, instead, to an adherent of the doctrine of spontaneous generation. This eminent author invites us,

> Let us assist in divine works. In a drop of sea-water, we see earliest creation recapitulated. God does not work in one way today and another tomorrow. I do not doubt that my little

> droplet of water will, by its transformations, tell me the history of the universe. Let us wait and observe. Who can foresee the droplet's history? Animal-plant, or plant-animal: which will be the first to emerge from it? Mightn't this droplet be the infusorium, the primordial monad who, by its own vibrations, soon becomes a vibrion, who, ascending rung by rung, becomes a polyp, a coral, a pearl, and perhaps in ten-thousand years attains the stature of an insect?
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> Will this droplet, or that which will become of it, be a vegetable fiber, a light, silky bit of down one would hardly even take for a living creature, but still, no less than the first hair of a newborn goddess, a sensitive, loving hair: the hair of Venus? This is no fable, this is natural history. This hair with two natures (vegetable and animal), the descendent of our droplet, is the ancestor of life itself. . .
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> These confervae, as they are called, are universally found in fresh water, and in salt water when it is calm. They begin the twin series of plants, marine plants and those which became terrestrial when the oceans formed. Above the water the family of the innumerable mushrooms arises, below the water that of confervae, algae, and similar plants.[4]

And so, gentlemen, we see that once the doctrine of spontaneous generation is admitted, the history of creation and the origins of the organic world follow without further ado. We simply take a drop of sea-water, and (as M. Michelet's tells us in beautiful prose) out of this water, which contains a bit of inanimate nitritic matter, sea-mucus, or, as he calls it, fertile jelly, the first creatures emerge by spontaneous generation. Transforming themselves bit by bit, they climb the ranks of creation, reaching, after, say, ten thousand years, the level of insects, and doubtless, after a hundred thousand years, the level of apes, and of Man himself.

Now, perhaps, you see the connection between the issue of spontaneous generation and the grander problems I enumerated at the beginning of my lecture. But gentlemen, as far as this subject is concerned, I think we've had quite enough poetry, enough fantasy, and enough of intuitive solutions. It is time for the true method, that of science, to assert and exercise its rights.

Religion, philosophy, atheism, materialism, and spiritualism have nothing to say here. I might also add: As a scientist, I needn't worry about them. The present question is a matter of fact. I address it without prejudice, as ready to declare in favor of spontaneous generations, should

[4]Michelet, La mer, second edition (Paris, 1861), pp. 116-117 [My translation. --ATL]

experience attest to their existence, as I am now persuaded that those who affirm them have their eyes bound.

> As my guide, I take the words of Buffon (and how true and inspired they are this time!). I aver that nothing would be so fine as to first establish a single principle, whence an explanation of the universe could be derived, and I allow that, for one fortunate enough to have divined this principle, all the effort required to produce experiments is for naught. But men of sense know well enough how vain and chimerical this notion is. . . It is by way of fine-grained, reasoned, and well-ordered experiments that we force nature to reveal her secrets. None of the other methods have ever succeeded. . . It will not do [for the physical scientist] to know what would occur under one or another hypothetical condition. . . [He] must know what is happening, what is before our eyes.[5]

Must it, then, be admitted that, in the debate over spontaneous generations, neither partisans nor opponents argue their cases by experiment? Or do you perhaps suppose that while, on the one side, we find only poets, romantics, and systematists, the other consists entirely of reasonable men who trust the results of experiment alone? No! Thank God, we are past that point; the scientific philosophy has a firmer grip on our mores and habits of thought, and no one on either side puts stock in anything but experiment. The proof may be found in an assertion by the eminent historian cited above. Addressing the doctrine that "Death gives rise to life," Michelet remarks that Harvey himself dared not dispute this ancient belief, for to his claim that "Everything comes from the egg" he added, "or from the dissolute elements of previous life." Michelet continues, "This is precisely the theory which has been revived, with such vigor, by the experiments of M. Pouchet."

Gentlemen, this sentence, situated as it is in a work of imagination with no pretensions to science, indeed, with no pretensions at all, save that of moving us with the spectacle of life's fecundity in the ocean's womb, strikes me as one of the finest tributes one could ever pay to the power of the experimental method. What does it matter that Michelet takes from science only those elements which accord with his preconceived notions, or that, in citing Pouchet's name, he fails to

[5]Buffon, "Préface" to Hales, Statique des végétaux (Paris, 1735), pp. iv-v.

mention that of his adversary? What I admire is simply the declaration that his thoughts are tied to the results of experiment.

Now, suppose I tell you that even in the work of Buffon--Buffon, a brilliant naturalist whose scientific career began with certain memorable experiments, and who, by consequence, became thoroughly accustomed to the habits of the experimental method, extolling it in the magnificent terms we have just heard--suppose I tell you that even in Buffon's work we find sentences enjoining us to "Seek an hypothesis on which to erect a system!" Perhaps now you understand what progress we have made when, in our own time, a romantic feels obliged to tell us, "Experiment is my guide." That is what I admire, and what moves me to observe that the scientific philosophy has become an integral part of common sense. Or, if this isn't proof enough, I challenge you to find a contemporary philosophical system which isn't, to put it vulgarly, fraught with science. The absence of such pays science the same tribute, in a different way; it is the same sign of the times. However, one shouldn't expect all those who appropriate the language of science to benefit equally from its intelligence.

But in any case, as far as the present debate is concerned, we find that each side has its experiments, each side its experimenters. The question may thus be reduced to the following terms: Who is wrong? Who experiments like Van Helmont, allowing mice, unbeknownst to him, to enter his flask of soiled linen, then proclaiming them the products of spontaneous generation? Is it you, the partisans of this doctrine, or I, your opponent? A precise resolution of this question is the next order of business.

No doubt, gentlemen, you expect me to rehearse all of the disputed experiments, but to do so would be to tire your patience needlessly. Instead, I will select a few of the most important experiments.

Most assuredly, if there are any facts the partisan of the doctrine of spontaneous generation must insist on, at all costs, they are those in virtue of which he believes himself entitled to dust off

his doctrine, as forgotten and defeated as it seemed at the end of the last century. It was M. Pouchet, the Director of the Rouen Museum of Natural History, an active member of the Academy of Sciences, who in 1858 told the Academy that he had succeeded in producing experiments which demonstrated, beyond the shadow of a doubt, the existence of microscopic creatures that entered the world without germs, and thus without parents resembling themselves.[6]

> This natural scientist tells us that
> Atmospheric gasses couldn't, and don't, carry the germs of these proto-organisms. In order to preempt all possible criticism on this score, I thought it best to demonstrate the evolution of organized beings under conditions in which artificial air had been substituted for atmospheric air.

Note what the author is trying to establish. Air neither is, nor could be, the bearer of the germs for these primitive organisms. For naturalists who deny the possibility of spontaneous generation suppose that the germs of microscopic creatures are present in the air, that air carries them, transporting them for some distance after snatching them from the breeding places of these little beings. Such, then is the hypothesis of the opponents of spontaneous generation; Pouchet, who seeks to refute it, adds, "In order to preempt all possible criticism on this score, I thought it best to demonstrate the evolution of organized beings under conditions in which artificial air had been substituted for atmospheric air." His approach is logical; and we shall see how Pouchet pursues it. His experiment is recounted as follows:

> A liter-flask is filled with boiling water and, having been hermetically sealed with greatest care, it is inverted over a vat of mercury; once the water has completely cooled, the flask is uncorked below the metal's surface, and a half-liter of pure oxygen is introduced.

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[6]Pouchet, F., "Note sur des proto-organismes végétaux et animaux, nés spontanément dans l'air artificiel et dans le gaz oxygène," Comptes rendus de l'Académie des sciences XLVII, 1858, pp. 979-982; Pouchet and Houzeau, "Expériences sur les générations spontanées, Deuxième partie: Développement de certains proto-organismes dans l'air artificiel," ibid., pp. 982-984.

Oxygen, of course, is the vital, salubrious component of air, as necessary to the lives of microscopic creatures as it is to that of higher animals and vegetables. But so far, the flask contains only pure water and oxygen; we must still produce the necessary infusion. "Next," Pouchet writes,

> a bit of hay massing ten grams, in a vial sealed with emery, is removed from an oven heated to 100°, where it has sat for thirty minutes, and is placed in the flask from below the surface of the mercury.

Pasteur demonstrates this experiment. Placing the vial under the surface of the mercury, he uncorks it and transfers the hay into the flask, inverted over the vat of mercury in advance.

This, gentlemen, is the experiment which has renewed interest in the doctrine of spontaneous generation.

And here is its result: after eight days, the infusion contains a fully developed mold. What is Pouchet's conclusion? Simply that the atmosphere didn't serve as the vehicle for these germs, these microscopic beings.

Well then, what objections might be leveled against Pouchet? Should we say to him, "Perhaps the oxygen you used contained these germs"? "No," he would reply, "for I extracted the oxygen from a chemical compound." So it really couldn't have harbored the germs. Should we say, "The water harbored the germs"? But he would only reply, "This water, exposed as it was to the air, might have contained germs; but I took care to pour it in the flask while it was boiling, and at that temperature, any germs would have lost their fecundity." Should we say, "It's the hay"? "But no," he replies, "the hay was taken from an oven heated to 100°." There remains one final objection, that there exist singular creatures known not to perish when heated to 100°. So he replies, "We'll fix that!" and heats the hay to 200°, 300°. . . he even claims, I believe, to have heated

it to the point of carbonization. I confess, thus conducted, the experiment is beyond reproach, but only with regard to the factors which attracted Pouchet's attention. I shall now demonstrate that there is a source of error of which Pouchet was not aware, a source which hardly anyone suspects, which no one would have suspected before him, and which renders his experiment completely illusory, as illusory as Van Helmont's flask of soiled linen; I will show you how the mice got in. What I will demonstrate is that, in all experiments of the sort presently at issue, the use of the vat of mercury must be proscribed absolutely. I shall demonstrate that, extraordinary as it may seem at first blush, it is the mercury which, in all such experiments, brings the germs into the flasks. Or rather, so as not to exceed what is now demonstrable fact, I shall say merely that it transports dust formerly suspended in the air.

No one among you, gentlemen, is ignorant of the fact that there is always dust suspended in the air. Dust is a domestic enemy familiar to everyone. Which one of you has failed to observe a ray of sunlight penetrating some crack in a blind or screen, thereby entering an otherwise poorly illuminated room? Which of you has failed to amuse himself by following with his eyes the capricious movement of those countless tiny bodies, so small in volume, so light in weight, that the air bears them as easily as smoke? The air in this room is replete with dust motes, with those tiny nothings which ought not always to be despised, for they sometimes carry sickness or death, in the form of typhus, cholera, yellow fever, and many other kinds of flux. Again, the air in this room is full of dust. Why don't we see it, except when it's illuminated? We fail to see the particles because they are so small, of such insignificant volume, that the few rays of light each of them casts toward our eyes are lost amidst the confusion of so many other rays, rays cast by even the smallest objects in this room, whose size is considerable when compared with that of these minuscule bodies. We can't see them now, for the same reason that, in broad daylight, we can't see the stars. But if we allow night to descend around us, and illuminate only the motes of dust, we will see them as clearly as the stars at night.

Let us darken this room, save for a single cone of light.

Now, gentlemen, you can see that the dust is everywhere in this room. If I had a few more minutes, I would ask you to approach the cone of light and examine it closely. You would notice that these dust-motes, though always agitated in one or another diverse ways, are constantly falling with greater or lesser speed: I believe you can make out a few of them, always a little lower one moment than the moment before, though they continue to float. As they float, they fall. In this way, dust covers our furniture, our clothes, all sorts of objects. At this very moment, dust falls on the objects before me: on these books, this paper, this table, and on the mercury in this vat.

Some of it fell just now, some an hour ago, or two hours, or this morning. Ever since this mercury emerged from its mine it has come into contact with dust, even leaving aside that dust introduced into the interior of the metal fluid by the diverse manipulations to which we subject it in our laboratories. Now, I will show you that this mercury can't be touched, whether by hand or by flask, without some of the dust now covering its surface entering the vat itself.

In order to make visible the results of the test to which I will now submit the surface of this vat of mercury, I will dim the lights again, illuminating only the vat, which I will sprinkle with a fairly large quantity of dust. Next, I will introduce some object into the mercury, say this glass rod. You will see the dust gathering and moving toward the point at which I introduced the glass rod, until it finally penetrates the space between the glass and the mercury; for mercury doesn't cling to glass.

Here, gentlemen, we have a much deeper vat, in which this same experiment may be performed to more startling effect. It consists in an iron tube one meter in depth, topped by a shallow basin. The entire surface of the mercury has been covered with dust. As I insert the glass rod, bit by bit, the mercury's surface clears, recovering its former metallic aspect. All of the dust is now contained within the metal fluid, in the lower part of the vase. As the rod is withdrawn, the surface once again becomes covered with dust.

What conclusion should we draw from this test, so simple to perform, but of such grave consequence for the point in question? We must conclude that it is impossible to perform any manipulations on a vat of mercury without introducing some of the dust covering its surface into its interior. To be sure, Pouchet eliminates one source of dust by using oxygen, artificial air; he eliminates water-borne germs, or germs which might be in the hay; but he has not eliminated the dust, and hence the germs, lodged on the surface of the mercury.

But note that my claims go beyond the warrant of this experiment. What I have just shown, once again, is that it is impossible to perform any manipulations on a vat of mercury without introducing some of the dust covering its surface into its interior. But when, in discussing the presence of dust, I infer to the presence of germs, I have gone further than this experiment can by itself. What, then, remains to be done? I must successfully establish that the dust carried by the air harbors the germs of lower organisms. Well, gentlemen, nothing could be simpler, anywhere on the globe, than to gather some of that air-borne dust, and examine it under a microscope so as to determine its composition, and that of its passengers.

Here we have a glass pipe, open at both extremities.

As you have just seen, there is dust in this room; in fact, the room is full of it. Suppose I were to place one end of this tube in my mouth, and inhale. In inhaling, I would cause some of the dust suspended in the air to enter my mouth and lungs. In order to amplify my inhalation, all I need do is to place one end of the tube in contact with a jar of water.

The sound of my inhalation thus becomes audible. The passage of dust into the interior of the tube which follows is thus made evident.

But if I place a small wad of cotton in one end of the tube, it should be clear that, so long as the cotton is not so tightly balled as to entirely impede the passage of air, the greater part of the dust, indeed, almost all of it, will remain within the cotton. Consider the experiment done; here is one of the wads of cotton thus treated. Those of you who are seated close by will notice that it is

practically black. Nothing could be more simple than to pour a little water in this dish, to which I add the wad of cotton. After massaging it with my fingers, I dispense a droplet of this water, which contains suspended dust, on a glass slide. When the droplet has evaporated, I add a second droplet, then a third, and so on. A large quantity of the dust formerly in the cotton has thus been deposited on the slide, which we will now examine under a microscope.--M. Duboscq will project the resulting picture of this dust collected from the atmosphere on our screen.

You will notice a number of amorphous objects: soot, bits of plaster, what might be fragments of linen, silk, or cotton, derived from your clothes. But in the midst of these amorphic objects one can make out such obviously organized corpuscles as these. It follows, then, that the amorphous dust carried by the atmosphere is always accompanied by such organized corpuscles. If we take their dimensions, and compare them with those of one of the mold seeds whose germination I showed you earlier, not even the most capable naturalist will be able to distinguish the slightest difference between the two objects. These, gentlemen, are the germs of microscopic beings.

I could, time permitting, also show you that it is possible to seed the corpuscles in suspension in the air in vials like these, which contain a organic infusion extremely subject to alteration upon contact with the atmosphere; the air now in the vials has, by virtue of having been introduced at an extremely high temperature, been made unsuited to the appearance of microscopic beings, but by breaking one end of a vial in a certain way we might expose the infusion to the atmosphere and find, after two or three days, that it has given rise to such microorganisms. On the other hand, I could gather air-borne particles on an asbestos pad, seeding the vial with them only after first having burned them in a flame, so as to destroy the corpuscles. In this case, the infusion would remain completely intact, as if it had never been seeded at all. It follows that these corpuscles are, quite obviously, germs; and in a moment you will have other, equally convincing proofs.

Gentlemen, I hasten to provide you with experiments so gripping that you cannot fail to

remember them, even if you forget the others.

Suppose we have relied on the vat of mercury, having recognized that its use gives rise to certain inevitable errors. This, gentlemen, is a perfectly pure infusion of organic matter, as clear as distilled water, and extremely subject to alteration. It was prepared today. Tomorrow, though, it will contain animalcules, little infusoria, or wisps of mold.

Now suppose I decant a portion of this infusion of organic material into a long-necked flask, such as this one. If I boil it and allow it to cool, then in a few days, it will contain fully-developed molds or infusoria. By boiling the infusion, I destroyed any germs there might have been in the liquid, or on the walls of the flask. But as this infusion remains in contact with the air, it undergoes alteration, like all such infusions.

But now suppose I repeat this experiment, but before boiling the liquid, I place the neck of the flask over a glazier's torch, allowing it to bend and stretch, while remaining open. I then boil the liquid, and allow it to cool. Now, the liquid in this second flask will remain completely unaltered, not just for two days, or three, or four, or even a month, a year, three years, or four! For the experiment just described has already been underway that long. The liquid remains completely pure, as clear as distilled water. What, then, is the difference between the two flasks? They both contain the same liquid, they both contain air, and they are both open. Why does one undergo alteration, while the other remains unchanged? Gentlemen, the only difference is this: In the case of the first flask, the germs contained in air-borne dust can fall down the neck of the flask, reaching the liquid, where they find appropriate nourishment, and proceed to develop. In the case of the second flask, however, it is impossible, or at least very difficult for air-borne dust to enter the flask, unless the air is extremely turbulent. Where does it go instead? It falls on the curved neck of the flask. When air enters the flask in accordance with the laws of diffusion, or as a result of relatively minor changes in temperature, it enters slowly, slowly enough that all of the dust and other solid particles it carries fall before they reach the opening, or along the early portions of the curved neck.

Gentlemen, this experiment is generous in its lessons. For notice that everything in the air, with the exception of dust, may enter the flask with extreme ease, thus coming into contact with the liquid. Whatever you imagine air to contain--electricity, magnetism, ozone, and perhaps even substances as yet unknown to us--it all passes through, reaching the infusion. The one thing which can't enter easily is dust, as demonstrated by the fact that, if I shake the flask violently two or three times, the infusion will, two or three days later, be seen to contain animalcules and mold. Why? Because the rapid entry of air brought the infusion into contact with dust.

Well, gentlemen, now I too could claim, showing you this liquid, that I had taken my drop of water out of the vastness of creation, and taken one replete with fertile jelly; or, to use the language of science, I could say that my droplet contains an abundance of those elements conducive to the development of the lower creatures. Oh, and how I wait, how I observe, questioning, demanding this drop to go about recapitulating the process of earliest creation; for what a spectacle that would be! But alas, the droplet remains mute, mute as it has been all the years since my experiment began. It remains thus because I have deprived it, and continue to deprive it, of the one thing it is not given to man to produce; I have deprived it or air-borne germs, or of life itself--for life is the germ, and the germ is life. The doctrine of spontaneous generation will never recover from the mortal blow inflicted by this experiment.

And yet, gentlemen, one might go further still.

The common occurrence of a certain sort of event has served to greatly obscure the topic presently at issue. As you know, grape juice remains unchanged, not fermenting, for so long as it avoids contact with the air. So long as the fruit remains attached to the vine, the juice inside it will not ferment. Once, however, the fruit has been crushed, its juice exposed to air, it undergoes alteration, and when examined under a microscope, reveals minute vegetation of the sort I showed you earlier.

Gay-Lussac was the first to recognize that the introduction of a single air-bubble into a large

quantity of grape juice was enough to bring about fermentation, and with it the production of this cryptogamic vegetation. Bit by bit, and without any carefully studied proofs, this fact about grape juice was extended to other infusions of organic matter. For example, it was claimed: If preserves are exposed to air, or even if a very small quantity of air is introduced into them, they will change, and may be shown under a microscope to contain infusoria and mold. Confronted with such claims, the partisans of the doctrine of spontaneous generation leveled the following objection against their opponents: How could there possibly be so many germs of microscopic creatures in the atmosphere, that even the tiniest air-bubble contains the germs of those which develop in every organic infusion? If there were that many, the air would be so full of organic matter as to form a dense fog. I believe Pouchet actually claimed that it would "produce a fog as dense as iron."

As I recall, when I began by investigation of this problem, this objection impressed me as extremely difficult to resolve. I simply couldn't see how each air-bubble could possible furnish each infusion with the germs best suited to it. This objection is serious, but only under one condition: it must be grounded in solid assumptions. Well, I will now show you that the assumption that a small quantity of air, taken from any point on the globe, is capable of fostering the development of microscopic beings in any infusion, is absolutely false.

I begin with a perfectly clear infusion of organic matter, so sensitive to alteration that tomorrow, provided the temperature is between 15°and 25°, you would find it completely clouded.

I place a certain quantity of this highly mutable infusion in a flask, stretch and bend the neck, and boil the liquid. The air formerly within the flask is forced out by the resulting steam. In addition, by heating the fluid to 100°, I destroy the viability of any germs the air might have imported.

When the liquid has been boiling for several minutes, I seal the neck with the aid of a glazier's torch, by melting the glass and allowing it to cool. Here you see a number of flasks prepared in this manner. Since these flasks are completely devoid of air, according both to the

doctrine of spontaneous generation, and to the opposing doctrine, it is impossible for the liquid contained therein to undergo alteration. Now suppose I break the neck of one such flask; you hear a whistling sound, made by the air as it forces its way in to fill the vacuum. I then reseal the flask. What does the flask contain now? A highly mutable infusion of organic matter, and what else? Ordinary air, the air of this room, which entered with considerable force, along with all the dust suspended in it.

If the doctrine of spontaneous generation is true, the liquid will undergo alteration; it cannot be otherwise. And indeed it does, but only in certain cases; for if I take, say twenty such vials, prepared in the same manner, then open them just as I just opened this one, seal them, and then allow them to incubate, there will always, repeated experiment has indefeasibly shown, be a certain number of flasks which remain unaltered, failing to develop a single animalcule, or the slightest mold. It follows, gentlemen, that the doctrine of spontaneous generation is false. For under the spontaneous generation hypothesis, what result could be more impossible? But under the opposing doctrine, what could be more natural, or, I might add, necessary? Indeed, if there are germs in the air, these germs must be distributed; it is clear that though there are some in one place, there needn't be any in another. Whoever affirms the aerial distribution of germs denies the continuous distribution of the cause of spontaneous generation. As you may have anticipated, the partisans of the doctrine of spontaneous generation respond, "That can't be right." In other words, they deny the evidence.

One might ask when the number of vials which remain unaltered will be in the majority. Their number must, obviously, be greater when the experiment is conducted far from inhabited regions, up in the mountains or down in the depths of the earth. One might try a glacier, say the glacier of Montblanc. It is clear that while the air there will harbor some dust, it will harbor less of it than that in this room.

Gentlemen, I have conducted all of these experiments. Among the vials I have shown you,

there are some which were opened in an apartment, in a laboratory, in a garden, in the Jura mountains, at eight hundred meters altitude, and higher. Others were opened on the Montblanc glacier. While there, I opened twenty. Only one underwent alteration. This experiment was conducted on September 22, 1860. Perhaps you think the liquid employed contains something which prevents it from altering? You need only break the neck of one of these vials, and tomorrow, or the day after at the latest, it will contain organisms, if the vial's temperature is between 20°and 25°. Nineteen of the twenty vials of Montanvert remain intact, along with fifteen out of the twenty opened in the Jura, and twelve of the twenty opened in the country at the foot of the Jura.

As you recall, my claim was that the further one travels from inhabited regions, the fewer germs there are in the air, and the greater the number of vials which remain unchanged.

Conversely, the further one ventures into inhabited regions, the greater the number of those which undergo change. I have made an interesting test of this claim, which I must relate to you. On my voyage to Montblanc, I carried with me an alcohol-jet torch for resealing my vials. On one occasion, I opened my vials, and prepared to reseal them, but strangely, the reflection of the sun off the ice, and the whiteness of the ice were such that it became impossible to make out the flame of the alcohol jet, made unsteady by the wind. I couldn't manage to keep the alcohol jet trained on the broken end of the neck long enough to seal the opening, for I couldn't see it. Why, you may ask, didn't you shade the lamp with your clothing? I might have, but my clothing could have proved an additional source of dust, and I would have run the risk of introducing into the sampled air precisely that which I wished to avoid. I was obliged to pass the night in the small inn of Montanvert, and to repeat the experiment the next day, before sunrise, with another series of twenty vials.

Only in the morning did I successfully reseal the thirty vials I had brought back to the inn, after they had been exposed for the whole night to the dust in my room. Well, of those thirty, only ten underwent alteration.

Gentlemen, if the lateness of the hour didn't oblige me to conclude this address, I could

show you how the most mutable liquids in the world, or at least those reputed to be such, blood and urine, when removed, by a special technique, from the veins or bladders of live, healthy animals and exposed to air, but air from which the dust and germs have been removed, remain completely unaltered. This experiment has been underway since March, 1863. The urine has been perfectly preserved, even down to its odor, without experiencing putrefaction of any kind. The same holds for the blood. And note that these liquids have never undergone any elevation in temperature. Up to now, I have always boiled the liquids used in such experiments; but the blood and urine remain just as they were when extracted from living animals. And so, once again, I conclude that the spontaneous generation of microscopic beings is a mere chimera.

No, there is not a single known circumstance in which microscopic beings may be asserted to have entered the world without germs, without parents resembling them. Those who think otherwise have been deluded by their poorly conducted experiments, full of errors they neither knew how to perceive, nor how to avoid.

And now, gentlemen, a fine topic presents itself for exploration. This is the role of those tiny beings which serve as agents of fermentation, putrefaction, and disorganization of everything on the surface of this globe which once had life, in the general economy of creation. This role is immense, marvelous, positively moving. One day, perhaps, I will be permitted to return here, to show you some results of this investigation. May God grant that it be in the presence of equally brilliant company!