Experimental biology, evolution, and artificially creating life around 1900: Research and reflections by Jacques Loeb

Presented in the Second Life® Embryo Physics Course

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By

Ute Deichmann

Jacques Loeb Centre for the History and Philosophy of the Life Sciences

Ben-Gurion University of the Negev

uted@bgu.ac.il

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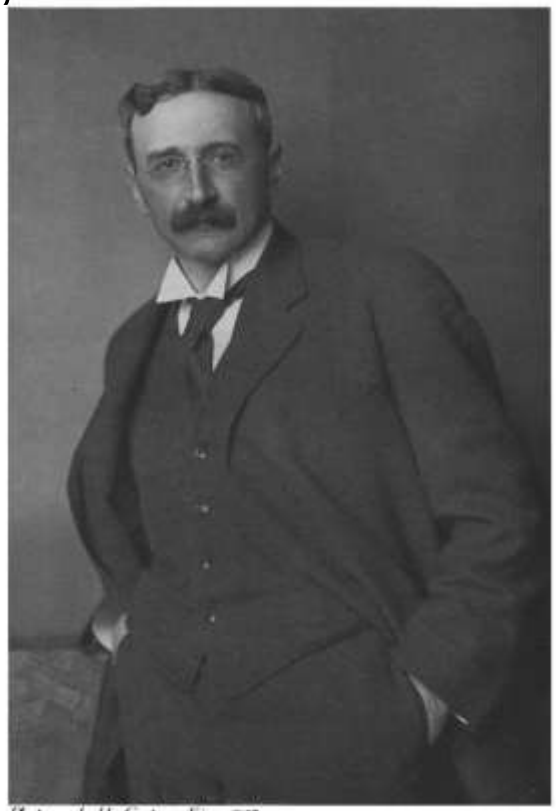


Jacques Loeb 1907

1. Introduction: Who was Jacques Loeb?
2. Loeb's passionate promotion of biology as an experimental science
3. Loeb and Darwinism
4. Loeb's reflections on the origin of life and synthesis of life from inanimate matter in the laboratory

1. Jacques Loeb

1859, Mayen -1924, Bermudas

physiologist, experimental biologist, biophysicist

- studied medicine in Berlin, Munich, Strasbourg, assistant (Würzburg, Strasbourg)
- 1891 emigration to US: Bryn Mawr, Univ. of Chicago and California (Berkeley)
- 1910 Rockefeller Institute for Medical Research

politically liberal

Loeb's methodology and scientific outlook was influenced by:

- mechanistic physiologists (e.g. Helmholtz),
- positivist-empiricist philosopher scientist Ernst Mach,
- the rise of Darwinism,
- his rejection of Chauvinism and irrationalism in Germany.

As a result, Loeb

- became a strong promoter of biology as an experimental science
- pursued the ideal of a materialistic and mechanistic biology (assumption: phenomena can be explained, at least in principle, on the basis of physics and chemistry)

Appraisal of Loeb by historians

"... the German émigré Jacques Loeb, America's emblem of pure *wissenschaft* ..." (L. Kay)

"By the turn of the century [Loeb] had come to symbolize both the appeal and temptation of open-ended experimentation among biologists in America" (P. Pauly)

Sinclair Lewis, Arrowsmith: Max Gottlieb modelled in part after Jacques Loeb

Headline in *San Francisco Examiner* 12 Nov. 1902

Figure 12. Page one headline in William Randolph Hearst's *San Francisco Examiner*. (12 November 1902).

2. Loeb's passionate promotion of biology as an experimental science

- Modern biology is "fundamentally an experimental and not a descriptive science": it is "either possible **to control a life phenomenon** to such an extent that we can produce it at desire (as, e.g., the contraction of an excised muscle)]; or we succeed in **finding the numerical relation between the conditions of the experiment and the biological result** (e.g. Mendel's law of heredity)." (1911)

Loeb's mechanistic vision:
"According to mechanistic science, it should be in the distant future possible **to reduce these specific life phenomena to the ultimate elements of all phenomena in nature, that is, motions of electrons, atoms, or molecules**." (1915)

Examples from Loeb ‘s research

A Control of life phenomena

- Behaviour

  Loeb applied Sachs's concept of tropism in plants to animals (e.g. caterpillars), thus experimentally controlling animal behaviour from without (refuting claims of the existence of mysterious instincts for self-preservation) (1888).

- Development

  Loeb developed a technique for inducing artificial parthenogenesis, “the substitution of well-known physicochemical agencies for the mysterious action of the spermatozoon” (1899).

University of California Yearbook 1905
"Exhibit No. 13: Genesis"

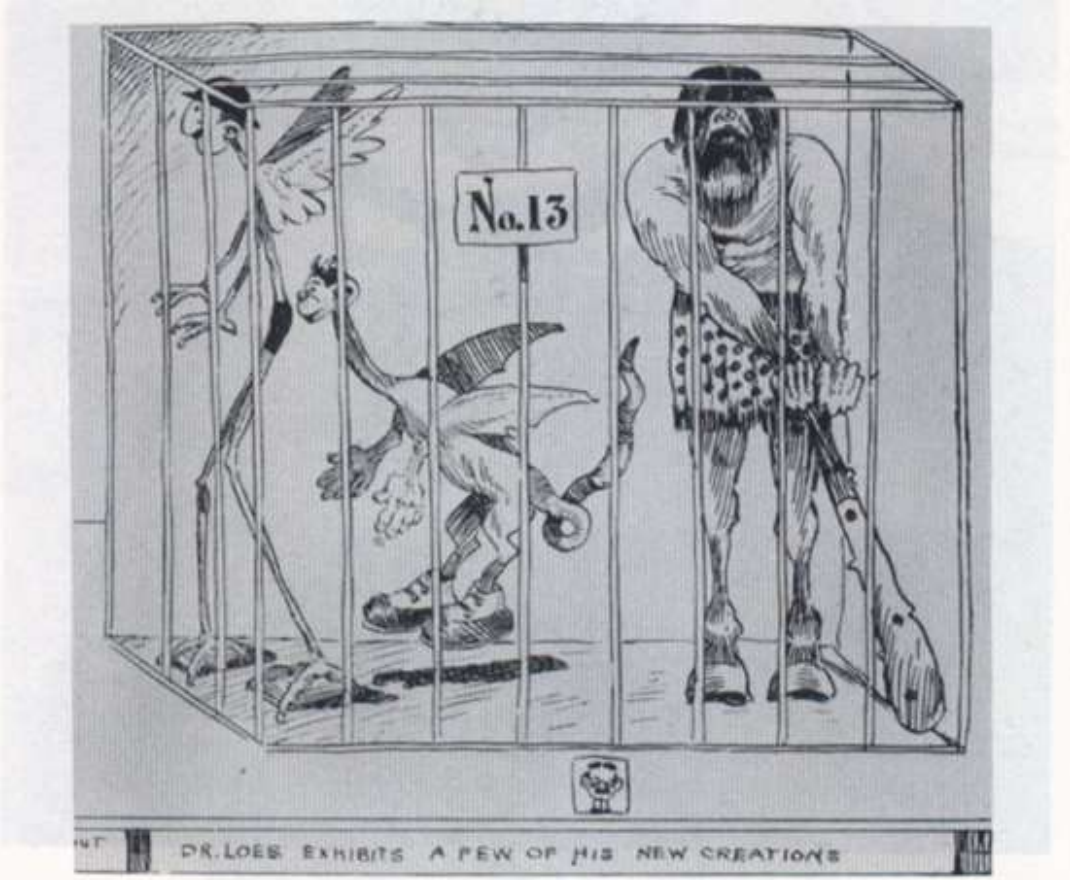


Figure 11. An illustration from the University of California yearbook, *The 1905 Blue and Gold*, p. 564. One of a series entitled, "The University's Exhibits at the St. Louis Exposition, Continued." It was captioned: "EXHIBIT 13—This group is entitled 'Genesis.' It effectually refutes the biblical legend of the Garden of Eden, and proves that man is descended from a grain of common salt (NaCl). The figure on the right represents an antediluvian Knockers Club; the central figure is a correct imitation of a prehistoric bat. The sweet-faced picture in the lower foreground is that of Dr. Loeb. All the people in the cage call him 'papa,' and he seems to like it. Dr. Loeb will accompany his family to St. Louis and deliver his

B Explaining basic life phenomena on the level of chemistry

- Loeb designed a program of biochemical genetics (1907 - 1915):
  - Genes are the determiners for a certain mass of enzymes;
  - geneticists should determine "**the chemical substances in the chromosomes** ... and **the mechanism by which these substances give rise to the hereditary character.**" (1911)

This strongly contrasted with the morphological approach that was employed by the vast majority of the cell biologists at the time.

B Explaining basic life phenomena on the level of chemistry

- Loeb anticipated the central role of DNA for heredity: "**Nuclein acid synthesis** as thread at which we find our way through the labyrinth of **the specific life processes**, i.e. growth by cell proliferation."(1907)
- "**Mechanism for the continuity of the hereditary substances**" identical with the "**secret of life**" (1909) the term belongs more "in the layman's vocabulary than in that of the scientist."
- The notion that DNA might be able to account for biological specificity (in today's terms: to carry biological information) was rejected by a most chemists and biochemists who assumed that DNA consisted of small uniform tetranucleotide molecules; only in 1950 the species specificity of DNA was demonstrated.

C Physical chemistry of proteins: Refutation of the existence of special colloidal laws governing the behaviour of proteins (1917-1924)

Claim of colloidal scientists:

- Proteins are colloidal aggregates of small molecules, do not react stoichiometrically (in exact proportions), do not dissolve as single molecules. Colloids form a world of “neglected dimensions”, follow special “colloid-chemical laws”. Biological systems cannot be “visualised in mechanistic terms”.

  (Wolfgang Ostwald: *Die Welt der vernachlässigten Dimensionen,* 1915)

Proteins and the theory of colloidal behavior (Loeb 1922)

- The colloidist concept of aggregation is superfluous, because
  - proteins obey the stoichiometric laws
  - the physical properties of colloidal proteins can be derived from existing theories of physical chemistry (e.g. the Donnan equilibrium; the theory of solution) if the influence of different pH values is regarded.

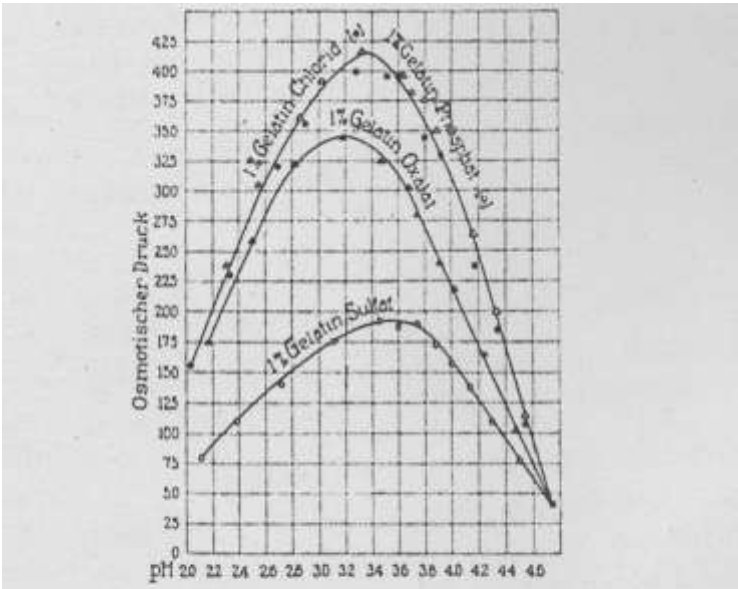


Fig. 2. Änderung des osmotischen Druckes der Eiweißlösungen unter dem Einfluß von Säuren. Der osmotische Druck hängt ab von dem *p*H der Eiweißlösung und der Valenz des Säureanions.

–- The chemistry of proteins is not different from that of the crystalloids.

- *Relating science and politics:* Loeb, “Mechanistic Science and Metaphysical Romance” (1915):
  - Wo. Ostwald’s views show links between romantic attitudes in science and militaristic nationalism,
  - the claim that the ‘neglected’ ‘middle country’ of colloids has a right to exist “paralleled German claims for the defence of ‘middle Europe’.”
  - Ostwald’s preface written “from the trenches” in France.
  - Wo. Ostwald’s efforts at disciplinary propagandising parallel the cultural imperialism of Wilhelm Ostwald (under the banner of “German organisation”) and his aim of a unification of Europe under German supremacy.

  - - -
- Wolfgang Ostwald's political chemistry during NS:
  – Visits of cultural propaganda between 1937 and 1941 to England, the US, Yugoslavia, Hungary and Rumania: the purge of Jews from German universities and society resembles a “recrystallisation”, necessary to gain purity.

Loeb on science and humanity:

- Scientific reasoning as rational reasoning is the only effective weapon against irrational political currents, e.g. the chauvinist and anti-Semitic propaganda of Dühring and Treitschke.
- “The question whether humanity wishes to be guided by mechanistic science or by metaphysical romance is, therefore, not only of merely academic importance. **What progress humanity has made, not only in physical welfare but also in the conquest of superstition and hatred, and in the formation of a correct view of life, it owes directly or indirectly to mechanistic science.”** (1915)

3. Loeb and Darwinism

Appreciation of Darwin

"Darwin's work has been compared to that of Copernicus and Galileo inasmuch as all these men freed the mind from the incubus of Aristotelian philosophy which, with the efficient co-operation of the church and the predatory system of economics, caused the stagnation, squalor, immorality, and misery of the Middle Ages.

Copernicus and Galileo were the first to deliver the intellect from the idea of a universe created for the purpose of man; and Darwin rendered a similar service by his insistence that accidental and not purposeful variations gave rise to the variety of organisms." (1916)

Dissatisfaction with the descriptive and speculative approaches of evolutionary biology around 1900

e.g. William Bateson 1902:

"In the Study of Evolution progress had well-nigh stopped.“

Loeb to Darwin scholars whose arguments he considered unscientific (1899):

“In science we could only take things for proven when they were based on quantitative experiments and from this point of view ours [i.e. around 1900] was not the era of Darwin but the era of Pasteur.”

- Loeb criticized in contemporary evolutionary biology:
  - zoologists ‘ attribution of human traits to animals and even a life-like nature to crystals (Haeckel)
  - progressive evolutionism (following Lamarck and Spencer), i.e. a belief in purposeful development and progress in nature and society
  - incompleteness of theory of natural selection (lack of physical-chemical explanations)
  - evolutionary biologists' inability to convincingly explain species transformation and to transform species at will.

“We cannot consider any theory of evolution as proved unless it permits us to transform at desire one species into another, and this has not yet been accomplished.”

The theory of selection is “incomplete since it disregards the physicochemical constitution of living matter about which little was known until recently." (Loeb 1916)

This is reminiscent of criticism of present-day evolutionary developmental biologists about the incompleteness of neo-Darwinism in regard to mechanisms of evolutionary change, in particular of the transformation of species and higher taxonomic groups.

Loeb rejected the methodological division of the phenomena of life into '<u>biological</u>' ('ontological'), e.g. behaviour, development, and evolution, **and '<u>physiological</u>'**

- Compare: Mayr (1962): <u>proximate</u> and <u>ultimate</u> causes; Dobzhansky (1964): <u>Cartesian</u>, (mechanistic) and <u>Darwinian</u> (historical) aspects of biology

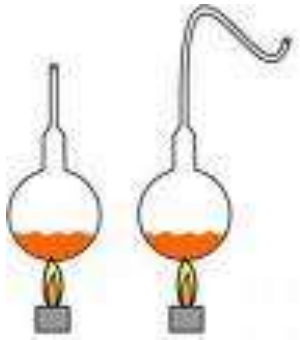
Loeb: Theories of evolution must be given an experimental basis: **Discoveries of Mendel and de Vries (mutations) "place before the experimental biologist the definite task of producing mutations by physico-chemical means"**. (1912)

4. Loeb's reflections on the origin of life and synthesis of life from inanimate matter in the laboratory

Mid-19th century

1. Belief in a special supernatural creation of all forms of life, which could not be dealt with scientifically
2. New forms of life continually arise from inanimate matter (spontaneous generation)

Pasteur's experiment (1859)

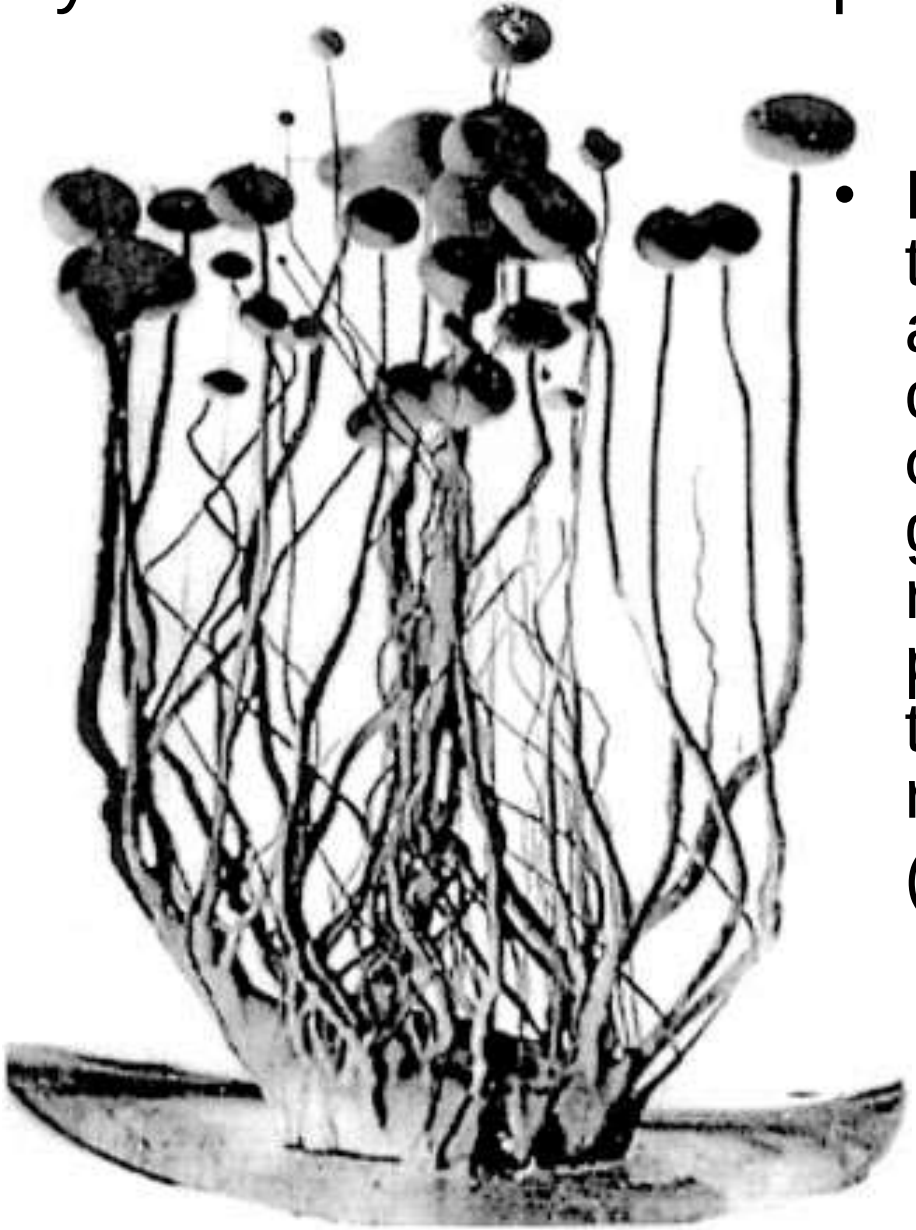


Aleksandr I. Oparin 1936: "Origin of Life"

- **“Pasteur’s proof that spontaneous generation does not occur in the solution used by him does not prove that a synthesis of living from dead matter is impossible under any conditions.** It is at least not inconceivable that in an earlier period of the earth’s history radioactivity, electrical discharges, and possibly also the action of volcanoes might have furnished the combination of circumstances under which living matter might have been formed.” (Loeb 1916)

To Loeb the question of the origin of life was closely related to that of synthesizing artificial life.

Physicists' claims to have produced artificial life



- E.g. Leduc (1912): claim to have produced artificial life by combining inorganic chemicals → osmotic growths that closely resembled fungi, lower plants and animals, able to grow and to reproduce by division

  (see Fox Keller 2002)

From Stéphane Leduc, *La Biologie Synthétique*, 1912

Fig 8. - Quatre périodes consécutives de l'évolution d'une même cellule artificielle.

Fig 10. - Cellule artificielle produite par un fragment de nitrate de calcium dans une solution de carbonate de sodium.

Fig 32. - Croissance osmotique de chlorure et nitrate de manganèse avec capsules terminales présentant un haut degré d'organisation.

Loeb's criticism of such claims:

- "The **purely morphological imitations of bacteria or cells which physicists have now and then proclaimed as artificially produced living beings**, or the play on words by which, e.g., the **regeneration of broken crystals and the regeneration of lost limbs** by a crustacean were declared identical will not appeal to the biologist. We know that **growth and development in animals and plants are determined by definite although complicated series of catenary chemical reactions, which result in the synthesis of a definite compound or group of compounds, namely *nucleins*.** →

- **“Whoever claims to have succeeded to making living matter from inanimate will have to prove that he has succeeded in producing nuclear material which acts as a ferment for its own synthesis and thus reproduces itself.** Nobody has thus far succeeded in this, although nothing warrants us in taking it for granted that this task is beyond the power of science.”

  Loeb 1909

Summary

Loeb‘s concept of "life"

- individual and species **specificity** of DNA and proteins
- "**synthetic powe**r" of transforming non-specific "building stones" into complicated compounds specific for each organism
- existence of **material capable of self-reproduction** in the cell nucleus

contradicted with that of scientists who claimed to have produced life purely by non-specific osmotic processes and disregarded the specificity of macromolecules.

Loeb's mechanistic biological research program

- strongly influenced leading figures of early 20th century experimental biology, e.g. Warburg, Morgan, Muller
- resulted in the very successful molecular biological approach
- is necessary but insufficient for the explanation of evolutionary changes, which requires the integration of this program with developmental-genetic research.

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