The proces of Digestion as Chemistry

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1. Introduction

William Beaumont was an American army doctor. It was there that the accidental injury to an army servant occurred upon which Beaumont's great experimental programme was dependent, and which will be described here. His studies on the chemistry digestion had become internationally famous in those years.

His extraordinary experiment might be a good starting point for discussions on the digestion item. In most countries digestion is a part of the compulsory part of scientific or biology programmes, for ages between 12 and 18. Discussions on food habits and diet are very actual themes in our western society, because they are closely linked to our health.

1. Historical View of Digestion

Hippocrates regarded digestion as a kind of *concoction*, or *stewing;* and many of his followers believed that it is affected in the stomach by the agency of heat alone, much in the same way as food is cooked over a fire. It is quite ascertained that heat favours the process, but it is pure absurdity to maintain that that agent alone will accomplish digestion.

Others of the older physiologists contended that **chymification** results from simple **fermentation** of the alimentary mass, and referred to the gas disengaged during difficult digestion, as a proof that the process of fermentation was going on.

The next theory which prevailed considered digestion to be the result of the **putrefactive process**. The single fact that the gastric juice not only arrests putrefaction, but even restores to sweetness meat in which that process is begun, is sufficient to demonstrate the wildness of such a supposition.

Experiments made by Spallanzani, Stevens, and others, show the solvent power of the gastric juice on food even out of the body. Spallanzani states, that when small portions of well-masticated beef or mutton are placed in a vial, with a proportion of gastric juice, and the requisite temperature and gentle agitation are secured by placing the vial in the armpit, the appearances presented at the end of a few hours are extremely analogous to those observed in the natural process of chymification; the meat being in both cases converted into the soft greyish mass of a consistence called chyme.

Another set of physiologists imagined that **trituration** would account best for all the changes occurring in the food during digestion; and consequently regarded the chyme as a sort of emulsion formed by the intimate mixture of the aliment with the juices of the stomach, just as an emulsion is formed by rubbing down almonds in a mortar.

The most sophisticated studies of digestion prior to those of the nineteenth century were the work of J.B. Van Helmont, a Flemish doctor. He was a man of great originality of thought, and with the manipulative skill and ingenuity to carry out empirical studies, and even experiments to test his theories of digestion. Most of his work is summed up in a strange but immensely popular work; the "Oriatrike or Physical Refined", published in English translation in 1662. People thought of digestion as a kind of cooking brought about by the heat of the stomach. Van Helmont knew that the proven acidity of stomach fluids were not enough to explain the digestion of meat and he introduced "ferments" responsible for specific action in the digestion process. This was very near our modern concept of an enzyme.

The five or six old theories of stomach digestion, concoction, putrefaction, trituration, fermentation and maceration were all discussed. Very much uncertainty existed as to the phenomena occurring during digestion in the stomach, the precise mode of action of the juice, the nature of the juice itself and its action outside the body. On all these points the observations of Beaumont brought clearness and light where there had been previously the greatest obscurity.

2. The life of William Beaumont

2.1 Early Years

The Beaumonts came from England to the American colonies in 1635. Dr. Beaumont's parents, Samuel and Lucretia, had a total of nine children; William was their second child, born in Lebanon, Connecticut on November 21, 1785. Lebanon was then the sixth largest town in Connecticut. In 1807, William left Lebanon for Champlain, where he became the town's schoolmaster and served as secretary for the local debating society.

2.2 Medical Training

In early 1809, William began "reading" under Dr. Benjamin Moore of Champlain. There were few medical schools then in the U.S., so it was common for potential doctors to be trained by reading medical subjects under the direction of an established doctor, and then paying for an apprenticeship with a doctor. In the spring of 1811, William began his apprenticeship with Dr. Benjamin Chandler and Dr. Truman Powell in St. Albans, Vermont; in 1812, the Third Medical Society of Vermont approved William to practice "Physic and Surgery."

2.3 Army Career

At age 26, Dr. William Beaumont enlisted as a surgeon's mate in the U.S. Army. He was assigned to the Sixth Infantry Regiment in Plattsburgh, New York. Soldiers lived in quite miserable conditions; hospitals were set up in buildings, barns, or even tents. After the war ended, Beaumont left the Army and in June 1815 he began private practice in Plattsburgh, NY, where he met his future wife, Deborah Green Platt.

He re-entered the Army in December 1819, this time as a post surgeon. He was sent to a place near the Canadian border.

In August 1821, Beaumont took a leave and travelled to Plattsburgh, where he and Deborah were married.

In 1826, Beaumont was assigned to Fort Howard, Green Bay, which was then in Michigan Territory. The medical problems he saw included fevers, diarrhoea, dysentery, and rheumatism; Beaumont connected the health issues with the area's weather. He thought that the numerous wounds and sprains he saw were caused by alcohol abuse, as soldiers in those days were rationed an entire "gill" of whiskey a day.

In 1828, he went to Prairie du Chien in Wisconsin and stayed four years. Fort Crawford's biggest medical problem was malaria, caused by mosquitoes and the area's problem of flooding each spring.

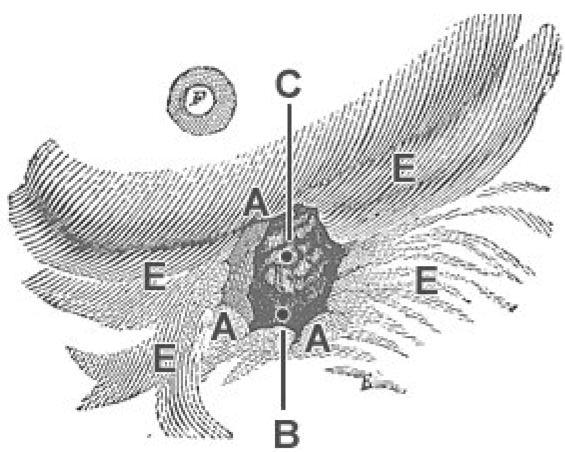
In July 1834, William Beaumont began service at his last Army post near St. Louis, Missouri. Beaumont participated in the new local medical society, which soon became the state medical society. His medical practice now earned him about $10,000 a year, despite a depression in the city. In March 1853, Dr. Beaumont slipped on an icy step while exiting a patient's home, hitting his head severely. He died on April 25 andwas buried in Bellefontaine Cemetery in St. Louis.

3. Experiments with Alexis st. Martin

On June 6, 1822 a French-Canadian voyageur named Alexis St. Martin was shot in the upper left abdomen; the musket wound was "more than the size of the palm of a man's hand," Beaumont wrote, and affected part of a lung, two ribs, and the stomach. Dr. Beaumont treated the wound, but he was repeatedly unsuccessful in fully closing the hole in St. Martin's stomach; for a while, the hole had to be covered to prevent food and drink from coming out. St. Martin was now unable to work, so in April 1823 Beaumont hired him as the family's live-in handyman.

The hole in St. Martin's side was a permanent *open gastric fistula*, large enough that Beaumont could insert his entire forefinger into the stomach cavity.

Diagram of Alexis St. Martin's wound (from Dr. Beaumont's book, *Experiments and Observations on the Gastric Juice and the Physiology of Digestion*, 1833)
"This engraving represents the appearance of the aperture with the valve depressed."

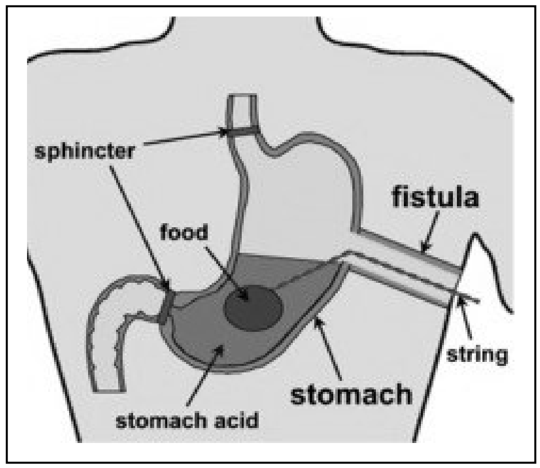


A	Edges of the aperture through the integuments and intercostals, on the inside and around which is the union of the lacerated edges of the perforated coats of the stomach with the intercostals and skin
B	The cavity of the stomach, when the valve is depressed.

C Valve, depressed within the cavity of the stomach.
E Cicatrices of the original wound.

"In a year from the time of the accident, the wound, with the exception of a fistulous aperture of the stomach and side, had completely cicatrized. This aperture was about 2 1/2 inches in circumference, and through it food and drink constantly extruded unless prevented by a tent-compress and bandage."

It was in 1825 that Dr. Beaumont — now stationed at Fort Niagara — began his experiments with St. Martin, becoming the first person to observe human digestion *as* it occurs in the stomach. Beaumont tied quarter-ounce pieces of food to the end of a silk string and dangled the food through the hole into St. Martin's stomach. The food items were "high seasoned alamode beef," raw salted lean beef, raw salted fat pork, raw lean fresh beef, boiled corned beef, stale bread, and raw cabbage. St. Martin went back to his household duties. Beaumont pulled out the string one, two, and three hours later, to observe the rate of digestion for the different foods. Five hours after he first put the food into St. Martin's stomach, Beaumont removed the food pieces because St. Martin was suffering stomach distress. The next day, St. Martin still had indigestion, which Beaumont treated.



On August 7, 1825, Beaumont had St. Martin fast for 17 hours, and then took the temperature of St. Martin's stomach (it was 100 °F) Beaumont removed gastric juice from St. Martin's stomach, then observed the rate of digestion of a piece of corned boiled beef "test-tube" style, while also placing the same-sized piece of meat directly into St. Martin's stomach. The stomach digested the meat in two hours; the vial of gastric juice took 10 hours (maintained at about 100 degrees. The next day, Beaumont repeated the experiments using boiled chicken, which he found digested slower than the beef. The experiments showed that gastric juice has solvent properties. In September, St. Martin returned home to Canada (where he married and had children), so Beaumont was unable to experiment on him further at this time.

Nine years later, in June 1829, Alexis St. Martin returned to the Beaumonts, this time bringing his wife and family to Fort Crawford. Beaumont started again with experiments in March 1830. One set of observations was to try to determine any relation between digestion and weather. By observing St. Martin on different days and times and in varying weather conditions. Beaumont saw that dry weather increases stomach temperature, and humid weather lowers it (a healthy stomach being 100 degrees).

In January 1831, Beaumont just observed the normal process of digestion in the stomach. St. Martin would eat a normal meal and resume his work, and Beaumont would periodically take samples from St. Martin's stomach.

Another experiment compared what happened to food placed in a vial of gastric juice (temperature not controlled), food placed in a container of water, and food eaten by St. Martin; he learned that gastric juice needed heat to digest (i.e., that cold gastric juice has no effect on food). Beaumont used more variety of food samples while at Fort Crawford; he found that vegetables are less digestible than other foods, and milk coagulates *before* the digestive process.

St. Martin sometimes became irritable doing experiments (it was stressful for him to have food removed from his stomach), and Beaumont observed that being angry can hinder one's digestion. In April 1831, St. Martin and his family left for their home in Canada.

In late 1832, Beaumont began a leave from the Army, intending to conduct further experiments on the digestive system. He located Alexis St. Martin in October, dropped off his wife Deborah and children in Plattsburgh, and travelled with St. Martin to Washington, D.C. Beaumont again tried different foods with St. Martin, including raw oysters, sausage, mutton, and "boiled salted fat pork." Beaumont focused on gastric juice, but did not study the importance of saliva on digestion; sometimes, he put food directly into St. Martin's stomach (once, he put in 12 raw oysters). He also observed that exercise helped the production and release of gastric juice. (Another limitation on Beaumont's work is that he could not obtain a chemical analysis of the gastric juice, as chemical analysis was severely limited in the mid-nineteenth century.)

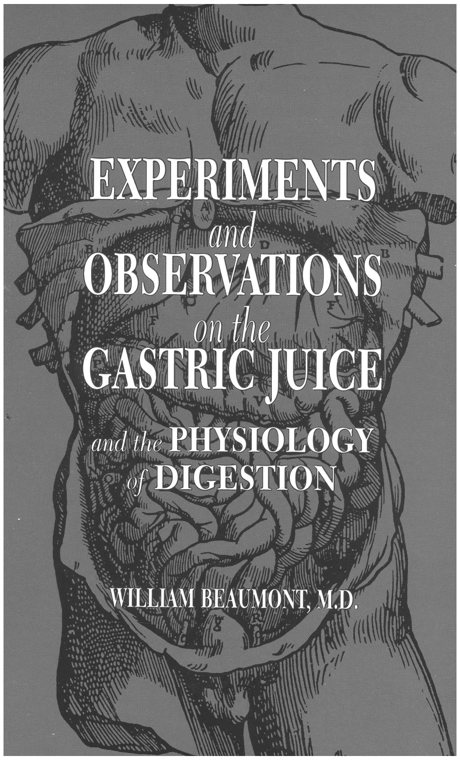
Alexis St. Martin lived 58 years after his accident. He died at age 86 on June 24, 1880 in Canada.

Photo of Alexis St. Martin at about age 81 years.

4. The Beaumont Papers

In mid-April 1833, Beaumont went to Plattsburgh, New York, where Beaumont was reunited with his family and began work on publishing his observations in a book, *"Experiments and Observations on the Gastric Juice and the Physiology of Digestion."* Dr. William Beaumont's cousin, Dr. Samuel Beaumont, had published a small newspaper prior to becoming a doctor himself (he apprenticed under William), so Samuel was quite helpful to William with the book's initial printing in 1833 (and with its second edition in 1846).

Dr. Samuel Beaumont



5. The importance of Beaumont's Work

Beaumont concluded that digestion is a chemical process and that gastric juice acts as a solvent. His work won wide acceptance. Generally ignorant of the debates raging in Europe over the physiology of human digestion and aligned with no school or ideology, Beaumont was viewed as an objective observer and an honest reporter. His book - self-published and dedicated to his mentor, Surgeon General Lovell - eventually sold more than 3,000 copies in its first edition. It became a trusted source for medical students and opened new avenues of research.

Since his death, doctors have paid tribute to Beaumont's work. In 1933, a prominent physiologist summed up Beaumont's contributions, writing: "[O]ne truly does not know gastric physiology and pathology as one should until Beaumont has been read critically and in toto." Sir William Osler described Beaumont as "the pioneer physiologist of this country," and Beaumont's biographer, Reginald Horsman, called him "America's first great medical scientist."

There had been other instances of artificial gastric fistula in man which had been made the subject of experimental study, but the case of St. Martin stands out from all others on account of the ability and care with which the experiments were conducted. The value of these experiments consists partly in the admirable opportunities for observation which Beaumont enjoyed, and partly in the candid and truth-seeking spirit in which all his inquiries seem to have been conducted. "It would be difficult to point out any observer who excels him in devotion to truth and freedom from the trammels of theory or prejudice. He tells plainly what he saw and leaves every one to draw his own inferences, or where he lays down conclusions he does so with a degree of modesty and fairness of which few perhaps in his circumstances would have been capable."

The following may be regarded as the most important of the results of Beaumont's observations.

- the accuracy and completeness of description of the gastric juice itself.
- the confirmation of the observation that the important acid of the gastric juice was the hydrochloric.

- the recognition of the fact that the essential elements of the gastric juice and the mucus were separate secretions.
- the establishment by direct observation of the profound influence on the secretion of the gastric juice and on digestion of mental disturbances.
- a more accurate and fuller comparative study of the digestion in the stomach with digestion outside the body, confirming in a most elaborate series of experiments the older observations of Spallanzani and Stevens.
- the first comprehensive and thorough study of the motions of the stomach, observations on which, indeed, are based the most of our present knowledge.
- a study of the digestibility of different articles of diet in the stomach, which remains today one of the most important contributions ever made to practical dietetics.

6. Didactic Value of Lab Experiments

- "Imitation" of the "stomac experiments" of Beaumont: find out how proteïns are digested catalysed by acids, enzymes and temperature
- Broaden these experiments with other digestion processes, such as the degradation of starch in saliva
- Virtual analysis of food: a computer programme gives insight nutrients, minerals, vitamins and energy value of different kinds of food

6.1 Didactic values

Food and digestion are certainly compulsory subjects in the education of pupils from 12 to 18 years old. The item might be presented in different ways: from basic understanding of the function of our digestive organs to the complex biochemical degradation of proteins, sugars and fats in higher years of the gymnasium.

The experiments of Beaumont are an example of thorough scientific work. A doctor, scientist works with great persistence and accuracy on his great project. He is not equipped with modern skills, but he takes notice of all his results in order to draw the exact conclusions.

Class experiments bring history alive and give insight in the practical problems of the Beaumont test. They encourage pupils and teachers broaden their knowledge of the digestion process.

Also the knowledge of "the scientific approach" starting for a practical experiment is good value for pupils: experiments, notations, conclusions, hypothesis, theory, law.

Pupils get insight in the chemical breakdown of food and about the influencing parameters.

Pupils get more conscious about their own diet and get to know the real "value" of different kinds of food, including their energy content.

6.2 Examples of experiments of the biochemical breakdown of proteins and sugars.

Enzymes make the body go! They are proteins which are made by the cell and which act as catalysts. Catalysts speed up chemical reactions. "Speed up" is, in a sense, an understatement. Without these catalysts, chemical reactions would take place so slowly that it would be as if they weren't taking place at all.

Most enzymes do their work in the cell. Others are produced by the cell but released to do their job elsewhere. Such is the case with the enzymes we will study today. Salivary amylase (also known by its' code name-ptyalin) is produced by cells in the salivary glands and released, through ducts, into your oral cavity. Pepsin is produced in the gastric glands and released through ducts into your stomach. Let's see what they do.

Procedure

1. **PEPSIN (Work in Groups of 4)**
    - Make an artificial stomach by placing a plastic sandwich bag inside a 250 mL beaker. Secure it with a rubber band over the lip of the beaker. Repeat this procedure three times so that you have 4 artificial stomachs. Label them: 1, 2, 3 and 4.
    - Follow the flow chart below in adding the appropriate amounts of each solution to each stomach. Use graduated cylinders for measuring fluid volumes.

	Stomach 1	**Stomach 2**	**Stomach 3**	**Stomach 4**
Water	80 mL	40 mL	40 mL	0 mL
HCl	0 mL	0 mL	40 mL	40 mL
Pepsin	0 mL	40 mL	0 mL	40 mL

    - **Keep each "stomach" in the the 40° C water bath for the duration of the laboratory, but place them in the 40° incubator just before you leave.**
    - Collect 4 small, equal size morsels of each the following foods:
      Hard boiled egg white
      Bread
      Beef Jerky
      Potato
    - Tie a small length of nylon thread to each piece of food. The thread should be long enough to suspend and periodically remove each morsel of food.
    - Suspend the 4 kinds of food in each of the stomachs.
    - Observe the suspended food after 15 minutes, 30 minutes, 45 minutes and 24 hours.

Q 1. Record your observation on a data table provided.

Q 2. Stomach #4 is intended to simulate the conditions of your stomach. Why was it necessary to set up each of the other three stomachs? Consider the importance of each one separately.

2. **SALIVARY AMYLASE (Work in Groups of 2)**
    - Number your test tubes 1, 2 and 3 and also place your initials on each tube (Do it toward the top of the tube.). Make small marks on each test tube about 1 and 2 cm from the bottom.
    - Follow the flow chart below in adding the appropriate amounts of each solution to each test tube. Use a funnel to collect the saliva. Do not count bubbles in the measurement. Carefully wash the funnel with soap and water after collecting the saliva.

	Tube 1	**Tube 2**	**Tube 3**
Water	1 cm	1 cm	0 cm
Saliva	1 cm	0 cm	1 cm
Starch	0 mL	1 cm	1 cm

- Place the test tubes in a warm water bath (37°C) which is on the front desk---NOT the boiling water bath which will be used for the Benedict's test later. Leave the tubes in the warm water for 10-15 minutes.
- Perform the Benedict's test on all three tubes. Place 20 drops of Benedict's solution in each test tube and place them in the boiling water. Wash the test tubes with soap and water after you are finished.

Q 3. Record your results.

Q 4. What do the results tell you about the contents of each test tube?

Q 5. If you got a positive Benedict's test in one of the test tubes, why was it also necessary to do the Benedict's test on the other two?

Review Questions:

1. The gastric glands of the stomach secrete pepsin and hydrochloric acid. What prevents this gastric juice from digesting itself?
2. Recently medical dogma regarding the cause of ulcers has changed. What was the "old view" and what is the "new view" to account for ulcers?

Conclusion: The "Pepsin" component of this lab is modified from "Looking Into The Stomach", Flinn Scientific, Inc. Batavia, Ill Biolabs¬ ©1992 BSCS.

Data Table-Pepsin Experiment:

Stomach 1	**Hard Boiled Egg White**	**Beef Jerky**	**Bread**	**Potato**
15 Minutes	.	.	.	.
30 Minutes	.	.	.	.
45 Minutes	.	.	.	.
24 Hours	.	.	.	.

Stomach 2	**Hard Boiled Egg White**	**Beef Jerky**	**Bread**	**Potato**
15 Minutes	.	.	.	.
30 Minutes	.	.	.	.
45 Minutes	.	.	.	.
24 Hours	.	.	.	.

Stomach 3	**Hard Boiled Egg White**	**Beef Jerky**	**Bread**	**Potato**
15 Minutes	.	.	.	.
30 Minutes	.	.	.	.
45 Minutes	.	.	.	.
24 Hours	.	.	.	.

Stomach 4	**Hard Boiled Egg White**	**Beef Jerky**	**Bread**	**Potato**
15 Minutes	.	.	.	.
30 Minutes	.	.	.	.

45 Minutes	.	.	.	.
24 Hours	.	.	.	.

Data Table-Amylase Experiment

	Tube 1	Tube 2	Tube 3
Benedict's Results	.	.	

6.3 Virtual food analysis and study of the individual diet

A few years ago, teachers from five schools from Belgium, Denmark, Italy, Norway and Spain agreed to gather their strength to find more information about the health and the lifestyle of their pupils in the Comenius H.E.L.P.-project, *"Health, lifestyle and physical condition of pupils"*. They wanted to compare the national lifestyle on different levels and they all shared the same worries about pupils: eating habits have been neglected and although many boys and girls are member of a sport club, the overall physical condition of youngsters is going down! Food containing too much saturated fat, giving rise to high cholesterol levels in the blood and too little physical exercise might be some of the causes of these diseases. All these considerations inspired them to make a "health balance" of pupils and to focus on this topic in lessons of physical education, science and informatics.

The part of the project that might be worth linking to this digestion-experiment is a national food list in English, Dutch, Norwegian, Spanish and Italian.. These lists are presented as questionnaire in an excel programme. Pupils write down the food or drink they want to examine and it is split up in the most important nutrients, minerals and vitamins. The total energy of each component is immediately calculated.

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