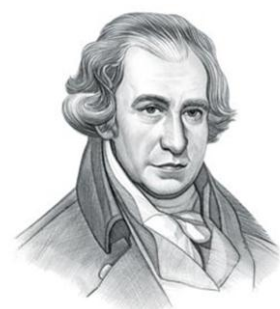
# How "Z" got its chemical name...

In this learning unit, we shall read about how people tried to understand chemical nature of a substance, and how these efforts led to knowledge we read about the nature of matter in our books today. Read the information given and try to answer the question given after it.

## Task 1: The "Z"

For ages, there was something which everyone had seen but no one knew what it is made of. Some said it was one of the purest substances of nature. Hence, they said it had nothing else in it. Many people tried breaking it down into components but were unsuccessful. Even heating it to high temperatures did not break it into components but converted it to an invisible form. People in different countries called it by different names. We will call it **Z**.

In 1777, a chemistry professor Mr. Macquer in France saw that on burning a gas in air, a liquid was formed on the lower surface of a dish held above it. Let us call this gas "**A**". Mr. John Warltire in England also observed the same phenomena. Due to cold climate in Europe, Macquer thought the liquid to be just water condensing from air. Four years later, an English priest, Dr. Priestly observed the same phenomena again. He wondered if burning of **A** in air is producing **Z** **!** and so he told it to his friends. At least three persons in Europe found this observation new and did experiments on it— Mr. Cavendish (a physicist in England), Mr. James Watt (an Engineer in Scotland), and Mr. Antonie Lavoisier (a tax collector and scientist in France).



Watt (Scotland) published his findings in 1784 that **Z** is obtained by combining **A** and another gas **B**.

Cavendish after detailed experiments, concluded in 1783 that burning of **A** in air indeed produces **Z**.


Lavoisier (France) heard the findings of Macquer and experimented with igniting **A** with gas **B** using spark and obtained **Z**. By 1783, he was the first to share this findings publically.

**Q 1**. What were the differences and similarities between the findings by Mr. Lavoisier, Mr. Watt, and Mr. Cavendish mentioned in the picture above?

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Mr. Lavoisier also measured the mass of **Z** formed and found it to be same as the sum of masses of **A** and **B** used.

Around that time, many scientists had found a new kind of energy which could break down liquids, they called it electricity. After lot of effort by several people, by 1800, an English surgeon Anthony Carlisle and his colleague William Nicholson showed that by electrolysis, the liquid "**Z"** could also be broken down into two substances "**A"** and "**B"**.

Thus, experiments done by many people in many countries together established that **Z** was not an element but ________________________________________________. (***Complete the sentence***)

## Task 2: The Mystery of Mass Ratio: The Concept of Atoms

Mr. Cavendish made more accurate mass measurements than Mr. Lavoisier and found that **Z** always had 11% **A** and 89% **B** by mass.
**Q 1**. Calculate the ratio of mass of **A** to mass of **B** in **Z** in terms of smallest whole numbers.

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**Q 2.** People have always tried to write shortcut notations to represent information. If people wanted to write the information about the mass ratio of **A** and **B** in **Z** as shorthand notation, how should they write it as?

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Many gases and liquids usually mixed in any proportions. However, **Z** had fixed proportion of masses of **A** and **B**. What did the fixed mass ratio tell about **A**, **B**, and **Z**?

Many philosophers since ancient history said that all matter consist of particles (called atoms) but no one had seen or measured mass of individual particles of **A** or **B**. Now even if they assumed that **A**, **B** and **Z** consisted of particles, the fixed mass ratio was still a problem.

If these substances consisted of particles, then there were two possibilities:
(i) different particles of a given substance had same mass.
(ii) different particles of a given substance had different masses.

**Q 3**. If different particles of **A** had different mass just like particles of sand, would the number of particles in any 100 g sample of **A** be always the same? Explain.

**Q 4**. In which of the above two possibilities, the mass ratio of **A** and **B** in **Z** would always be the same? Explain. What other condition about the particle combinations in **Z** is necessary to explain the constant mass ratio?

Around 1800, a pharmacist in France, Mr. Joseph Louis Proust gave a hypothesis that a fixed composition of elements is a characteristic property for compounds. Thus compounds were different from mixtures, which could have varying composition. Since many substances were known by then that had fixed composition, this hypothesis of Mr. Proust came to be known as the law of constant proportion for compounds.

If all particles in an element have same mass, then masses of **A** and **B** in a certain amount of **Z** can be written as

Mass of **A** in **Z** = mass of 1 particle of **A** × number of **A** particles in **Z**

Mass of **B** in **Z** = mass of 1 particle of **B** × number of **B** particles in **Z**

and ratio of mass of **A** to mass of **B** in **Z** can be expressed as:

$$\frac{\text{Mass of } \mathbf{A} \text{ in } \mathbf{Z}}{\text{Mass of } \mathbf{B} \text{ in } \mathbf{Z}} = \frac{\text{mass of 1 particle of } \mathbf{A}}{\text{mass of 1 particle of } \mathbf{B}} \times \frac{\text{number of } \mathbf{A} \text{ particles in } \mathbf{Z}}{\text{number of } \mathbf{B} \text{ particles in } \mathbf{Z}}$$

The ratio on the left hand side for **Z** was fixed (as obtained from the experiments). Therefore, if one knew the mass ratio of individual particles of **A** and **B**, then the ratio of number of **A** and **B** particles could be obtained, and vice versa.

Two students, Kamal and Amina were reading this history and were trying to find possible ratio of number of particles of **A** and **B** in **Z**.

**Q 4.** Amina wanted to consider the simplest possibility that the mass of an **A** particle is same as that of a **B** particle. For Amina's assumption, find the ratio of number of particles of **A** to **B** in **Z**.

**Q 5**. Amina chose shorthand symbol of **Z** as $\mathbf{A}_x\mathbf{B}_y$, where x and y are number of particles of **A** and **B** in a particle of **Z**, respectively. Then what would Amina write the symbol of **Z** as?

**Q 6**. Kamal assumed that the mass of an **A** particle is 2 times the mass of a **B** particle. For Kamal's assumption, what would be the symbol of **Z**?

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Now let us go back in $18^{th}$ century and see what assumptions the scientists made about **Z.**
In 1787, a 21 year old professor of mathematics and natural philosophy in England, Mr. John Dalton, developed an unusual interest in nature of the atmosphere. He continued study on atmospheric gases even after losing his job in 1789. Based on his experiments, he also proposed that all substances are made of particles. He also made a very unusual and bold assertion giving a face to the modern atomic theory:

- all particles of a substance are alike with respect to mass and properties.
- particles of different elements are different in mass.

In 1804, Mr. Dalton published a book "*A New System of Chemical Philosophy*". In this book, he wrote that, the ratio of the number of particles of elements in a compound can be expressed as a simple whole number ratio. For **Z**, he made an assumption that the ratio of number of particles of **A** and **B** should be 1:1, and the symbol of **Z** should be **AB**.

**Q 7**. With Dalton's assumed symbol (**AB**) for **Z** and assuming that the mass of a particle of **A** is 1 unit, what would be the mass of a particle of **B**?

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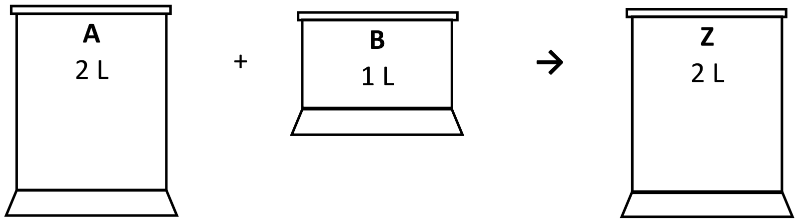
## Task 3: The Mystery of Volume Ratios: The Concept of Molecules

Around the same time in England only, Mr. Cavendish and Mr. Priestly found a relationship between volumes of reacting gases used to make **Z**. This finding was later confirmed in 1808 by a French Chemist Mr. Joseph Gay-Lussac. They found that to form **Z**, the volume of **A** used at atmospheric pressure was 2 times than that of **B** used at the same temperature. Further, 2 L of **A** combined with 1 L of **B** to give 2 L of gaseous **Z** at the same temperature.




The volume ratio of **A** and **B** that was obtained from electrolysis of **Z** was also found to be same (2:1) and fixed at a given temperature and atmospheric pressure.

**Q 1**. Above information indicates that the average volume occupied by particles of **A** at atmospheric pressure and same temperature is always the same! Explain how?

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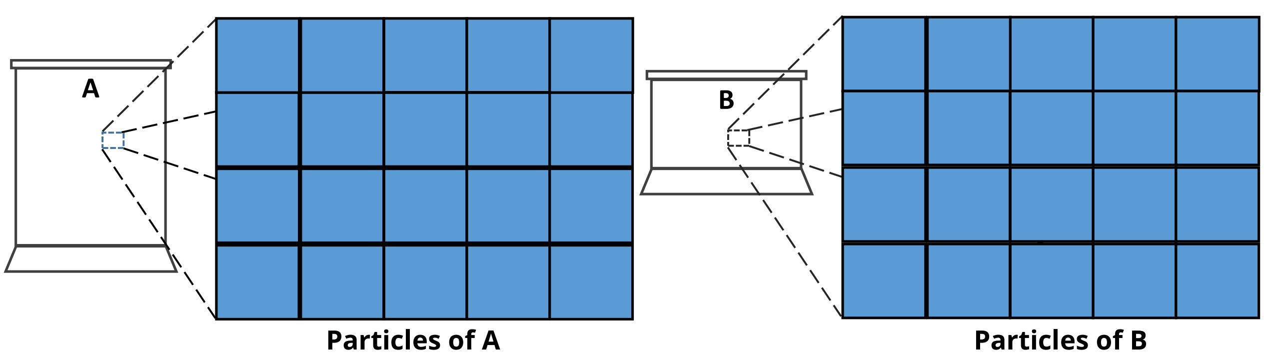
This was puzzling because mass percentage of **B** used for **Z** was higher and volume was lower than that of **A**. Mr. Dalton struggled to imagine how particles in different substances were arranged in space which could lead to this volume ratio. Since no one had ever seen how particles are arranged in space in gases, he and other imagined particles to occupy cubical spaces. He also thought that the particles must be stacked over each other.

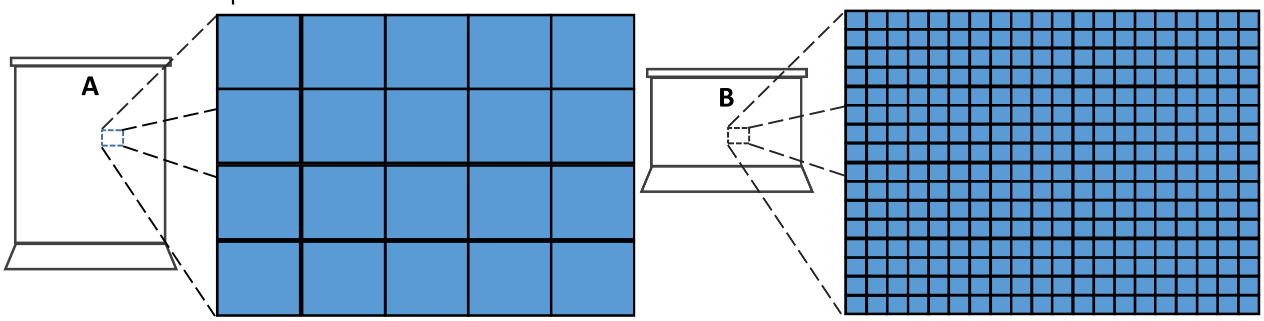
If we consider above experimental data, the following possibilities emerge:

**Possibility I**: The average size of a particle of **B** was same as that of a particle of **A** but particles of **B** are heavier than **A**.



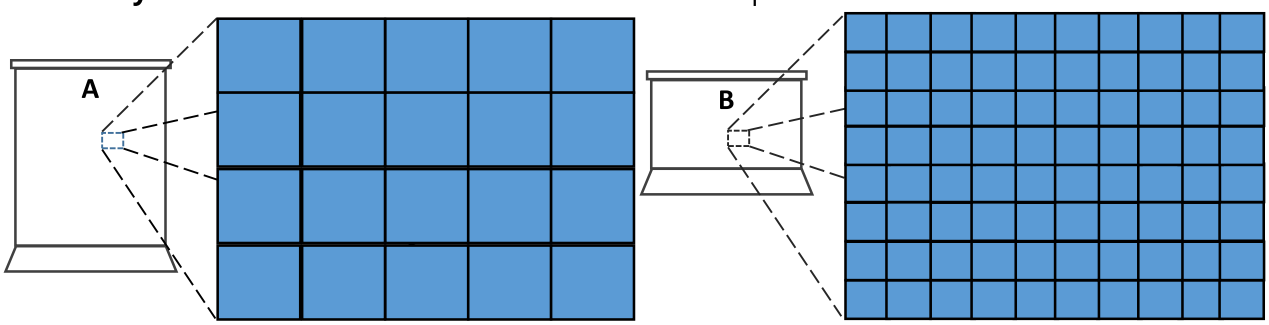

**Possibility II**: Particles of **B** have same mass as particles of **A** but the average size of particles of

**B** is less than the particles of **A**.



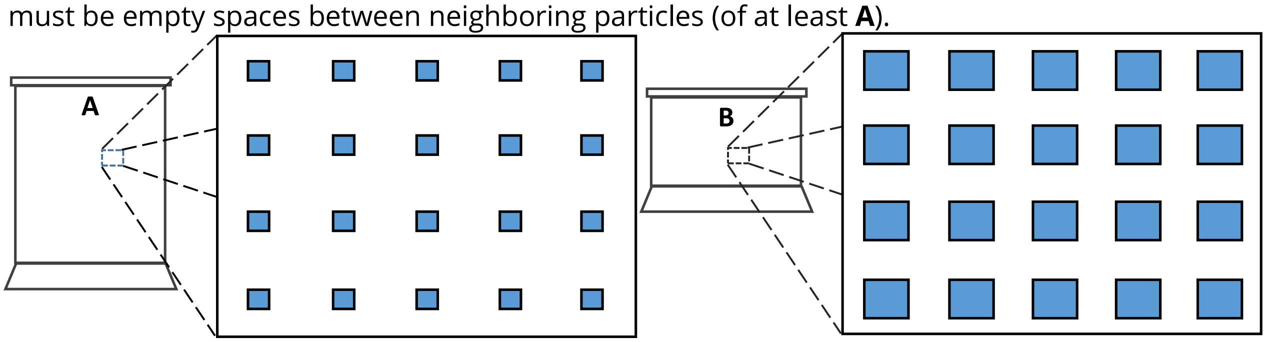

**Particles of A** **Particles of B**

**Possibility III**: Particles of **B** are heavier but smaller than particles of **A**.




**Particles of A** **Particles of B**

**Possibility IV**: Particles of **B** are heavier as well as bigger than particles of **A**. In such case, there must be empty spaces between neighboring particles (of at least **A**).




**Particles of A** **Particles of B**

**Q2**. Which of the above possibility is likely to be more correct and why?

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**Q 3**. Draw any other picture of arrangement of particles of **A** and **B** you can think of:

**Particles of A** **Particles of B**

Unfortunately, the data presented so far was insufficient to establish the chemical symbol for **Z**. No one could count the number of particles in a given mass or volume of a gas. Based on other experiments, Mr. Gay-Lussac hypothesized that equal volumes of different gases should be containing equal number of particles.

**Q 4**. If equal volumes of two gases have same number of particles, then which of the above possibilities (**I** to **IV**) have to be WRONG?

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**Q 5**. With the above assumption, 2 L of **A** should contain twice the number of particles as in 1 L of **B**. If two particles of **A** combine with one particle of **B** to give 1 particle of **Z**, then how many L of gaseous **Z** should be obtained with 2 L of **A** and 1 L of **B** . Explain.

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Mr. Dalton did not accept Mr. Gay-Lussac's reasoning because if 1 L of **A** had same number of particles as 1 L of **B**, and if two particles of **A** combine with one particle of **B** then 2 L of gaseous **Z** could not be obtained. He argued that if particles of different elements had different masses then their sizes should also be different.

**Q 6**. If particles of different elements have different sizes, then which of the above possibilities (**I** to **IV**) have to be WRONG?

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In 1811, an Italian physics professor Mr. Amedo Avogadro published a solution to the volume problem. He wrote that if the particles of elements could break into two half particles, then two particles of **A** would combine with one particle of **B** to give two particles of **Z**. Thus, Professor Avogadro brought the idea of molecules and that molecules can break into two smaller particles (which now everyone knows as atoms). In other words, what was being considered as (fundamental) particles so far were molecules, which could break further to give atoms.

 

In addition, Mr. Avogadro also supported Mr. Gay Lussac's reasoning and showed the necessity to assume that "equal volumes of all gases at the same pressure and temperature contain equal number of particles" to explain the above experimental observations.

**Q 7**. If we accept Mr. Avogadro's hypothesis about half-particles (atoms), then what must be the ratio of number of half-particles of **A** and **B** in **Z**. Thus, what should be the chemical symbol of **Z**?

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## Task 4: The Major Learnings

**Q 1**. If the formula of **Z** is as per Avogadro's hypothesis and mass of an atom of **A** is taken to be 1 unit, then what must be the mass of an atom of **B**.

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**Q 2**. How many years did it take after the first laboratoty synthesis of **Z** to establish its modern chemical formula?

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**Q 3**. Can you now figure out what is compound **Z**?

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**Q 4**.List the major experimental facts and assumptions that were necessary to arrive at the modern chemical symbol (which we also know as chemical formula) of **Z**.
Experimental Observations:

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Assumptions:

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## References:

a) Henry Cavendish's 1784 paper on synthesis of water:
http://rstl.royalsocietypublishing.org/content/74/119.

b) James Watt's 1784 paper on synthesis of water: http://rstl.royalsocietypublishing.org/content/74/329.
c) Antoine Lavoisier' 1783 report: Observations sur la Physique, 23, 452-455 (1783) on water being a compound.
d) Pictures were sourced from http://www.pci.tu-bs.de/aggericke/Personen/Gaylussac_Biography.html, www.worldatlas.com/webimage/countrys/eu.htm, fr.wikipedia.org/wiki/Fichier:Antoine_Laurent_de_Lavoisier.png