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P3_4 A Near Fatal Lecture

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Abstract

Despite rising carbon dioxide levels, it is not currently high enough to cause any long-term effects on the body. There is no common consensus as to what concentrations of CO_2 can cause hypercapnia, but this tends to occur at concentrations greater than 5%, with levels of over 10% often leading to fatalities [1]. We investigate how long it would take for a typical lecture hall to reach this 5% critical level, which begins to affect consciousness, with a standard physics cohort just by breathing, which we find this length of time is around 6.5 hours.

Introduction

While carbon dioxide poisoning (also known as hypercapnia) can be mitigated, with sufficient ventilation and space, as of 2015 it has been estimated that around 90 people in the USA alone die each year due to confined spaces [1], a value which has seemingly not decreased since the 1980s. Here, we will investigate the time it would take for an insufficiently ventilated lecture theatre to reach 5% CO_2 concentration due to exhalation from a standard physics cohort, which would likely affect the consciousness of those present in the room.

Method and Results

To find the length of this lecture, we first need to consider the volume of a standard lecture theatre for our chosen cohort size. For a capacity of 100 students, the front ceiling height should be 12ft (3.66m), with the rear ceiling height as 8ft (2.44m)[2]. To make it easier to read the screen, students should sit a maximum of 20m from the screen, and taking a ratio of 1:4 for the width to depth of the room[3], we calculate the depth of the lecture theatre as 5m. Thus, the total volume of air in the lecture theatre is 305m^3.

The average concentration of CO_2 in the atmosphere is 0.04%, [4] and hypercapnia occurs at 5% [1]. This means the change in the concentration of CO_2 due to breathing needs to be at least 4.96%, equating to 15.1m^3 by volume. Here, we assume that the volume of CO_2 exhaled replaces the inhaled O_2 volume, so that the amount of gas in the room is constant. We also assume that the room is sealed so that there is no gas transfer with the external environment.

Next, we need to find the number of moles of CO_2 that this volume equates to. We can do this with the following equation:

$$PV = nRT, \tag{1}$$

Where the pressure is P=101kPa, volume, V=15.1m^3, n is the number of moles of CO_2, R=8.314 J mol^{-1}K^{-1} is the molar gas constant, and the temperature is T=293K. Here, we have assumed standard conditions. We find that we need 627 moles of CO_2 to reach 5% concentration. We can find the mass of CO_2 formed from the exhalation, using the following equation:

$$M = nM_r, \tag{2}$$

Where M_r is the molar mass of CO_2 (44g mol^{-1}) and M is the mass in grams. Thus, we find that the mass of CO_2 added is 27.6kg.

Next, we consider how much CO_2 a human produces via respiration, and this is around 2.3lbs (1.04kg) per day [5], 104kg for 100 people. There are 86,400 seconds in a day, meaning that we can calculate the average total mass of CO_2 produced each second, simply dividing $100kg$ by 86,400 seconds. This gives a rate of 1.20x10^{-3}kgs^{-1}. Finally, we divide the mass of CO_2 needed to reach the threshold concentration (27.6kg) by the average rate. We find that the time taken for everyone to fall unconscious due to CO_2 poisoning to be 22,900 seconds, or 6 hours and 22 minutes.

Discussion and Conclusion

Realistically, a lecture would not last this long. Rather than consistent short-term exposure, carbon dioxide poisoning is likely to appear from long-term exposure to heightened CO_2 levels. This also depends on the CO_2 tolerance of an individual, which varies from person to person [1]. Our results suggest that once this threshold concentration is met, everyone will immediately fall unconscious, but with this new information, this may not be the case. Those that are less tolerant may risk falling unconscious long before this. It stands to reason that we have calculated a time at which more serious hypercapnia symptoms appear.

We have assumed that the lecture theatre takes an optimal shape, but not all lecture theatres will be the optimal size. It is possible that these rooms differ in size from our estimates, changing the time to reach this critical CO_2 concentration of 5%. Other factors may also affect this time, such as temperature, pressure, average respiration rate of a cohort, and presence of furniture.

In conclusion, while this is not necessarily a realistic scenario, it does highlight the importance of well-ventilated spaces. Research suggests that concentrations as low as 0.25% can begin to impair cognitive functions, such as concentration and memory [6]. Furthermore, mortality rates in the USA due to confined spaces appear to have not decreased over the past few decades [1], suggesting that this issue has not sufficiently been mitigated. We advocate that CO_2 poisoning be taken more seriously, as an aim to educate and increase awareness of the potential dangers of poorly ventilated confined spaces.

References

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