

Technical Note

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Melting of Ice Block as an Alternative Method of Radioactivity Demonstration

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Abstract

This work is aimed at looking for an alternative, non-hazardous, highly sustainable and economically cheap substance that could be used such that its rate of decrement is analogous to radioactive decay as a substitute for practical demonstration of radioactivity and deduction of the associated constants. The ice block was used in place of radioactive substance. It was placed in a netlike wire mesh with hanger constructed for that purpose hung on a spring balance calibrated to read zero before the placement of the ice block. The reading of the initial weight of the ice block was taken and recorded while timing of its melting was carried out separately at intervals of 10 minutes and 15 minutes. The weight of the ice block left was recorded and the data analyzed. It was observed, in each case, that the weight – time relationships had exponential decay characteristic analogous to the radioactive decay in accordance with the empirical formula governing radioactivity, irrespective of the interval of timing adopted. Deduction of melting constant analogous to radioactive decay constant, as well as half-life of the block used was achievable with this method. It could be concluded that ice block is an auspicious non-radioactive substance that could be employed as a substitute for experimental/practical demonstration for making teaching and learning of radioactivity concept or topic learner-centered for a better appreciation and comprehension. Ice block is a very good substitute for radioactive substance for the purpose of practical/experimental demonstration of radioactivity.

Keywords Exponential decay, half-life, Learner-centered, Melting constant, Radioactive substance

1. Introduction

Following the discovery of radioactivity by Henri Becquerel in 1896 [1], some early scientists began to make various scientific contributions towards expanding awareness on the concept. In the present century, radioactivity is applicable in pharmacokinetic, pharmacodynamic, chemotherapy, medicine, Physics, Chemistry, environmental studies, petroleum exploration, hydrology, geology, geosciences, cosmic studies, power plant, and military among others.

According to Garg and Garg [2], radioactivity (or radiation generated as a result of a break up of nucleus of radioactive atom which is too large, making it unstable and leading to the atom being changed to atom of some other element with a lower mass, may be of alpha particles, beta particles and gamma radiation) is found to be hazardous to life. Studies revealed that living beings are exposed continually to ionizing radiations generated within and outside the earth and these are present in natural sources



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including oil, rocks, water, air, food, cosmic rays coming to the earth from outer space [3 – 5]. This information collaborates the report of the International Atomic Energy [6]. For one to know radioactivity, the person must have the understanding and knowledge of items or substances that contain radioactive elements as well as their risk and usefulness in everyday life. Some researchers performed in-situ investigation and reported on exposure to radioactive effects within places like Ikot Ekpene [7], Ikot Akpaden Campus of Akwa Ibom State University [8], and Uyo Unity Park [9] all of which are in Nigeria, emphasizing that 0.05 Sv/y is the allowable environmental radioactivity baseline limit value.

Despite some of the associated risky or damaging tendencies, radioactive elements are also very useful in the society. Such benefits are found in their application in agriculture, healthcare, power generation, sterilization among others. For example, ionizing radiation is useful for provision of energy as well as medical and agricultural purposes [10]. Radioactive decay process can be used for estimation of excretion rates in addition to steady-state concentration for drugs in pharmacokinetic and medicine [11]. Borowy [12] asserted that a good understanding of zero and first order kinetics is a basic requirement in clinical context. This assertion is in tandem with the reports of Maafi et al [13] and Mcmartin et al [14]. Jain and Rao [15] noted that knowledge of atomic theory is useful in understanding the nature of ionizing radiation hazards and means of protection against them. All these underscore the importance of radioactivity and the necessity to have a broad knowledge of it. Based on such consideration, radioactivity is made a teaching and learning subject topic especially in Physics and Chemistry even at the higher levels of Education. Unfortunately, students (learners) are not given any experimental lesson on radioactivity and the associated parameters (such as decay constant and half-life) notwithstanding the benefits, thus making them have poor cognition of the concept [16]. So far, several scientists and educators have advocated that effort should not be limited to lecturing activities but lesson should be motivated through factual issues and to demonstrate important experimental approach [17 - 22]. However, there is still a dearth of information on practical experiments and demonstrations that could provide solution to the existing challenge and ensure effective explanation of radioactivity to students. Consequently, students view nuclear radiation as being dangerous, a situation that goes with emotional fear [16, 23] and makes them regard that reasoning about the phenomenon is context-dependent [24 – 28].

The aim of this work, therefore, is to produce ice block from ordinary clean water and then use it to demonstrate

radioactivity phenomenon. Interestingly, water is a free gift of nature and also one of the divine treasures. It is the most essential and necessary requirement of life that is commonly-available and can be obtained free or with a very cheap cost [29 – 33]. In line with the remark of Lord Kelvin that measurement of what one speaks about and its actual expression in numbers brings about knowledge of the concept, a research in this direction was carried out using methylated spirit [34]. The choice of water as the non-radioactive substance for the present study is due to the fact that it is the best in terms of human health and also, very economically cheap to acquire with high sustainability. In addition, ice block can undergo reduction in size and weight, a phenomenon that is analogous to radioactive decay backed up with a devised scientific technique that can make its use in teaching and learning of radioactivity and the allied concepts practical and learner-centered for better understanding by the students. The design of this research is structured to also address the associated concepts of radioactivity such as half-life and decay constant, explaining how the rate at which radioactive substance decays and obeys the law of decrement backed up by the applicable empirical formula for radioactive decay.

2. Empirical consideration

Bequerel's work evolved around qualitative consideration, but the work of Rutherford and Soddy considered more of quantitative laws derived from their practical experiments, showing experimental nature of radioactive decay, as expressed by several authors including Radvanyi and Villain [1], Vasudeva [35], and Etuk et al [34] thus

$$N = N_0 e^{-\lambda t} \quad (1)$$

where N represents the number of radioactive atoms present at time, t and N_0 represents the number of radioactive atoms present at time t_0 (before decay) while λ is known as decay constant (the probability for any particular atom to disintegrate per unit time).

The half-life period, $T_{1/2}$ for a specific species of radioactive atom is such that

$$T_{1/2} = \frac{\ln 2}{\lambda} \quad (2)$$

which becomes

$$T_{1/2} = \frac{0.693}{\lambda} \quad (3)$$

Pomme et al [36], among other authors, reported that probabilistic arguments can be used for exponential decay. Empirically, the decay rate coefficient, λ which is an expression of constancy, is an essential and acceptable condition for exponential decay. This is highly collaborated by the reports of Radvanyi and Villain [1], and Bonnetti

and Gugliemetti [37].

For the purpose of teaching and learning, weight is adopted in this research to express the decay function as

$$W = W_0 e^{-\lambda t} \quad (4)$$

where W represents weight of the ice block left after timing in each case and W_0 represents the initial weight of the ice block before timing while t is time of melting of the ice block.

The parameters W and W_0 are considered analogous to N and N_0 in this study. Also, λ could be considered defrozing or melting constant (analogous to decay constant).

3. Materials and Methods

3.1 Materials

The materials used in this research included spring balance, retort stand (with base, boss head and clamp), ice block (obtained by freezing ordinary drinkable water in a refrigerator), digital stop watch, and mercury-in-glass thermometer. The water was transparent, colorless, and without smell.

3.2 Method

Figure 1 shows the experimental setup used in this research. The spring balance was suspended from a fixed position on the retort stand. At its lower end, a net-like wire mesh with hanger (constructed for that purpose) was hung. The balance was calibrated to read zero before the ice block was placed in the net wire. All the ice block samples used in this study were produced from equal volumes of the water using the same refrigerator and it was ensured that there blocks were completely formed in each case. This was necessary for the purpose of similarity of the ice block samples. The experiment was performed on two different days, using the same setup. On each day, 10 minutes and 15 minutes intervals were adopted for timing of the melting process. The processes were implemented in the laboratory at 28 °C each day. Care was also taken to ensure that the process was not influenced by excessive wind blow or heat. As the ice block was melting, the readings on the spring balance were noted at the considered intervals until no significant variation was observed.

For each timing category, the data obtained on both days were tested statistically using one-way analysis of variance (ANOVA) at 0.05 level of significance as well as Pearson-Product Moment Correlation Coefficient (PPMCC). In order to deduce the melting constant and initial weight of the ice block, the decay function was linearized to obtain the following form

$$\ln W = \ln W_0 - \lambda t \quad (5)$$

The associated parameters were determined after which they were used to plot a suitable graph for the deduction purpose.

From the plot of W against t , a model expressing the melting function was developed with the aid of Origin software (Version 2019b). Also, the initial weight of the ice block and melting constant were deduced. The values obtained from the graph were compared with those deduced from the model.

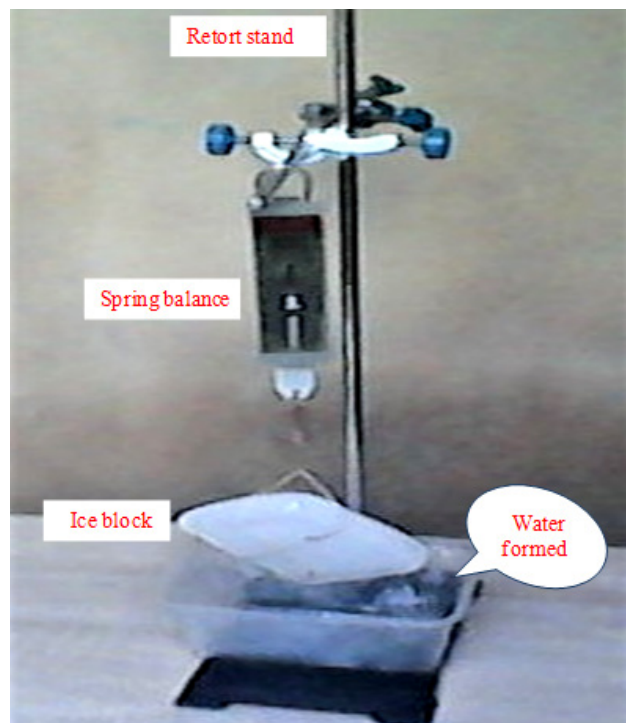


Figure 1: Experimental setup for the melting process

4. Results and Discussion

The data obtained for the 10 minutes timing intervals for both days are as shown in Table 1. In Table 2, the data obtained for the 15 minutes timing intervals are presented. Considering the data in the two tables, it is obvious that the remaining weight of the ice block is time-dependent, decreasing with increase in time or duration allowed for the defrosting irrespective of the day.

The PPMCC values obtained for the paired variables on both days for the considered timing intervals are positive and very high. Specifically, the results show that the melting or defrosting behavior of ice block on Day 1 and Day 2 agree by about 99.71 % for 10 minutes consideration of timing and 99.72 % when considering timing intervals of 15 minutes. These results strongly suggest that the experiment is reproducible.

Table 1: Experimental data for the 10 minutes timing intervals

Time, t (Minutes)	Reading on the spring balance, W (N)		$\ln W$		Data from the statistical tests	
	Day 1	Day 2	Day 1	Day 2	PPMCC	F -value
0.0	4.00	4.00	1.386	1.386	0.9972	0.0084 (4.7472)
10.0	3.60	3.70	1.281	1.308		
20.0	3.25	3.35	1.179	1.209		
30.0	2.80	3.00	1.030	1.099		
40.0	2.55	2.65	0.936	0.975		
50.0	2.25	2.30	0.811	0.833		
60.0	2.05	2.00	0.718	0.693		
70.0	1.80	1.75	0.588	0.560		
80.0	1.60	1.45	0.470	0.372		
90.0	1.40	1.20	0.336	0.182		
100.0	1.20	1.00	0.182	0.000		
110.0	1.00	0.80	0.000	-0.223		
120.0	0.85	0.65	-0.163	-0.431		

Value in parenthesis is critical F -value for the ANOVA

Table 2: Experimental data for the 15 minutes timing intervals

Time, t (Minutes)	Reading on the spring balance, W (N)		$\ln W$		Data from the statistical tests	
	Day 1	Day 2	Day 1	Day 2	PPMCC	F -value
0.0	4.00	4.00	1.386	1.386	0.9971	0.0134 (5.3177)
15.0	3.40	3.45	1.224	1.238		
30.0	2.80	3.00	1.030	1.099		
45.0	2.40	2.40	0.875	0.875		
60.0	2.05	2.00	0.718	0.693		
75.0	1.70	1.55	0.531	0.438		
90.0	1.40	1.20	0.336	0.182		
105.0	1.10	0.90	0.095	-0.105		
120.0	0.85	0.65	-0.163	-0.431		

Value in parenthesis is critical F -value for the ANOVA

The ANOVA results show that irrespective of the timing intervals considered, the calculated F -value does not exceed the critical F -value. This implies that at the 0.05 level of significance, there is no significant difference between the weight of ice block remaining on Day 1 and the weight of it remaining on Day 2 for either timing interval of its melting or defrosting.

Figure 2 reveals that the relationship between the weight of the remaining ice water and the melting time is that of exponential decrement exactly similar to the case of radioactivity which arises from radioactive decay. This is irrespective of the timing interval for the melting or defrosting of the ice block got from freezing of water. The behavior is analogous to radioactive decay, therefore ra-

dioactive in nature. In all the cases, the melting function agrees well with the empirical relationship expressed as equation 4 in this research.

Figure 3 illustrates the plots of $\ln W$ against t . These plots lend credence to the assertion above. Deductions from the plots give melting constants, λ and initial weight, W_0 of the ice block. The values of these parameters are shown in Table 3. The values of W_0 are within 4.04 and 4.49 N bracket. Approximately, these values are 4.0 N, which agrees with the spring balance reading at $t = 0$ (being the initial or starting weight of the ice block). For the λ , the model-derived and graphically-deduced values are within 0.01193 and 0.0148 N/min bracket.

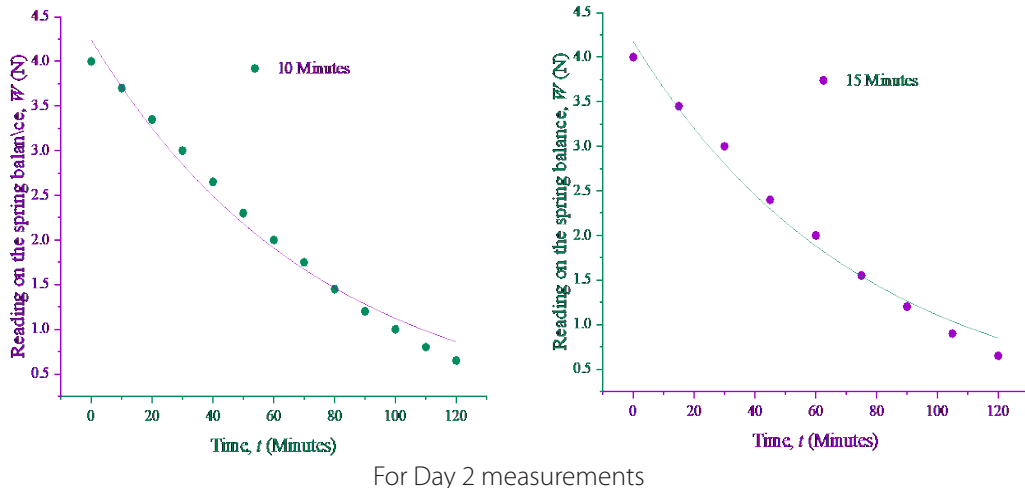
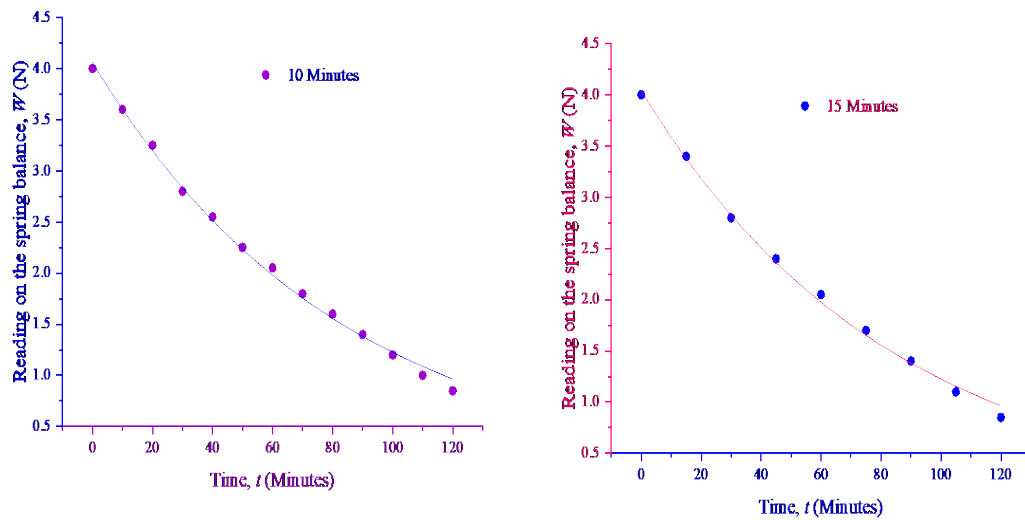


Figure 2: Plots of remaining ice block weight against time of melting

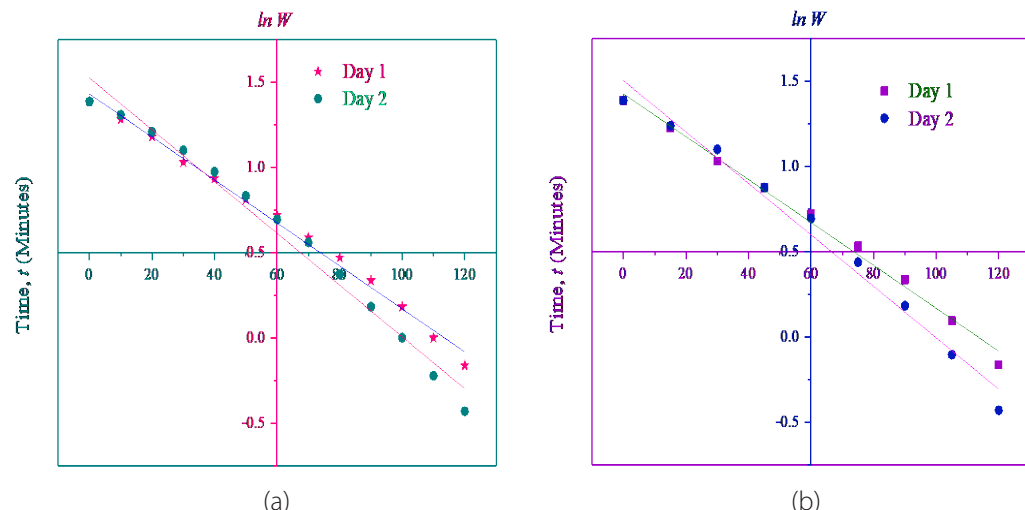


Figure 3: Plots of $\ln W$ against t for timing intervals of (a) 10 minutes (b) 15 minutes

Based on the decay constant obtained, the half-life $T_{(1/2)}$ could be determined in accordance with equation 3. For the studied material (ice block) in this research, it could be inferred that it took half the weight of the ice block 55.0 minutes to melt as per deductions from the plots in respect of 10 minutes intervals for Day 1 and Day 2. In the cases of the 15 minutes timing intervals, it 46.5 to 46.8 minutes for the same amount of the ice block to melt based on deductions from the plots. On the basis of the results obtained by employing the model, the time for half the weight of the ice block to melt in terms of 10 minutes and 15 minutes timing intervals is found to be 57.8 minutes and 58.0 minutes for Day 1 and 52.1 minutes and 52.3 minutes for Day 2 respectively.

It can therefore be adjudged based on the results that in all, it took half of the weight of the ice block a minimum of 47 minutes and maximum of 58 minutes to melt. This is analogous to half-life concept in radioactivity. Meaning that, it would take the ice block such time to get a half of its initial weight to melt in a consecutive manner. Since the W and W_o appropriated for N and N_o in the present study, it is therefore obvious that the mechanism of experiment in the study is similar to the principle relating to radioactivity. Above all, it must be acknowledged here that the values of melting constant of the ice block may slightly change depending on temperature under which the experiment is carried out. Change in temperature notwithstanding, but the trending remains and holds true. This demonstration gives credence to the reports that experimental activities reveal the presence of radionuclide in seafloor, groundwater, ocean water, rain water and other environmental substance [38, 39]. Comparatively, the approach described in this research gives a better understanding with concrete evidence compared to either the computer simulations applied by Dekay and Maidl [16] or the Protective Action Model utilized in previous studies for the purpose of forecasting the behavior of individual in different risk situations, including pollution of cities, cumulative disaster exposure as well as environmental hazard [41, 42]. It can as well enable medical practitioners to have a practical understanding of half-life concept for further clinical decisions making and application [43].

5. Conclusion

The results of this study have revealed that experimental data during the melting process displayed agreed with the exponential decrement characteristic of radioactive decay. Radioactivity concept, including decay constant (analogous to melting constant in this study) and half-life (similar to time taken by half of the weight of the ice block to melt in successive manner) can be demonstrated experimentally using the timing of melting of ice block pro-

cess. The weights of ice block after each timing interval of melting were observed to associate with melting time such that there is no significant difference in correlation coefficients between choice of 10 minutes and 15 minutes timing intervals for Day 1 and Day 2, agreeing by almost 99.71 % for 10 minutes consideration of timing and 99.72 % for 15 minutes interval consideration of timing. This suggests reproducible nature of the experiment.

More so, the ANOVA results show that the calculated F-values do not exceed the critical F-value, irrespective of the timing intervals considered in the present study, implies that at 0.05 level of significance, there is no significant difference between weights of the ice block remaining on Day 1 and the weights of it remaining on Day 2 for either timing interval of its melting. It can therefore be concluded that the ice block is a potential substitute or an alternative substance for demonstration of the concept of radioactivity. Though further study on the consideration of the influence of environmental factors is proposed, it is obvious from the findings that ice block can be used as described in this work for practical/experimental demonstration of radioactivity, hence making it learner-centered and real for a better appreciation and understanding of the concept in Chemistry and Physics at college levels.

6. Recommendation

The non-harmful, non-toxic, and non-corrosive effect of ice block made from drinkable/clean water, coupled with the economically very cheap or costless means of obtaining it, as well as its unlimited sustainability, makes ice block obtained by freezing of the water a favored substitute for practical demonstration of radioactivity in higher schools and Colleges. Also, the method developed and the associated apparatus make it more recommendable for learner-centered radioactivity teaching.

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Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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