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Ralph H. Thomas

September 1981

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THE VALUE OF $\bar{W}(E)$ IN NITROGEN FOR HIGH ENERGY IONS

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Abstract: Recently published values by the author of the average energy required to produce an ion pair in nitrogen by monoenergetic high energy ions, $\bar{W}(E)$, are analyzed by means of Analysis of Variance Techniques. These techniques point to somewhat different conclusions from those revealed in the original paper. In which the authors suggested it was not possible to distinguish between the values of $\bar{W}(E)$ obtained for three species of ion (C^{6+} , Ne^{10+} and Ar^{10+}). Analysis of the data by means of a one way classification suggests that there may be a difference in $\bar{W}(E)$ values for the three species of ion at a level of significance of 0.05.

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1. INTRODUCTION

Thomas et.al., have reported measurements of $\bar{w}(E)$ (the average energy required to produce an ion pair by monoenergetic high-energy ions in nitrogen) (1). Three species of ion were used - C^{6+} , Ne^{10+} and Ar^{18+} . In the case of C^{6+} ions measurements were made at a fixed location in a parallel plate ionization chamber, while for the other two ion species measurements were determined in different regions of the chamber. A summary of the data is included in the original reference (1).

Thomas et. al., summarized the values of $\bar{w}(E)$ obtained as:

- (1) 250 Mev/amu C^{6+} ions: 36.4 ± 0.6 ev
- (2) 375 Mev/amu Ne^{10+} ions: 35.4 ± 0.8 ev
- (3) 479 Mev/amu Ar^{18+} ions: 34.7 ± 0.5 ev

In general $\bar{w}(E)$ is expected to be a complex function of both the charge state and velocity of the ion. At high energies, however, these effects are small and Thomas et al reported that it was not possible to draw firm conclusions concerning the dependence of $\bar{w}(E)$ upon charge state of the ion and assumed that the values of $\bar{w}(E)$ did not differ significantly from one another. By combining the three sets of data they obtained an overall value of $\bar{w}(E) = 35.4 \pm 0.3$ ev. It is possible to investigate the conclusions of the authors by Analysis of Variance Techniques - specifically by a one way classification (2).

A second uncertainty in the original data as pointed out in the original paper and elsewhere (3,4) is that, a possible source of systematic error in the technique used is that the δ -rays produced in the nitrogen gas of the chamber have ranges greater than the dimensions of the region over which the measurement was made. The measured charges collected in each region of the chamber might not correlate with ion fluence. Thomas et. al., concluded this effect was less than 4 percent overall and would produce errors of less than 1

percent in values of $\bar{w}(E)$ averaged over the entire chamber. Analysis of variance by a two way classification enables the variation of $\bar{w}(E)$ with chamber location to be investigated for the data obtained with Ne^{10+} and Ar^{18+} ions.

This note summarizes the application of one and two way classification Analysis of Variance Techniques to the original data to investigate these two points. Full details of the complete analysis are reported elsewhere (5).

Analysis for Equal Values of $\bar{w}(E)$ by One-Way Classification

All the data reported in the original reference for the three species of ion may be utilized in testing the hypothesis that the mean values of $\bar{w}(E)$ for each ion are equal. Table 1 summarizes the pertinent data and Table 2 gives the analysis of variance data.

TABLE 1
Summary of Data

	POPULATIONS*		
	1	2	3
Sample Mean, $\bar{x}_i$	36.3	35.5	34.8
Sample Variance, S_i^2	1.30	1.66	0.80
Sample Size, N_i	6	5	11
$\sum x_{ij}$	217.7	177.5	382.5
$\sum x_{ij}^2$	7905.39	6307.89	13308.55

$$\sum \sum x_{ij} = 777.7$$

$$N = 22$$

$$\sum \sum x_{ij}^2 = 27521.83$$

$$\bar{x} = 35.35$$

*Footnote: 1 - C^{6+} , 2 - Ne^{10+} , 3 - Ar^{18+} .

TABLE 2
Analysis of Variance - One way Classification

SOURCE	SUM OF SQUARES	df	MEAN SQUARE	F
Between	8.855	2	4.4275	3.95
Within	21.280	19	1.1200	
Total	30.135	21		

Application of a Fisher Test rejects the hypothesis of equal mean value of $\bar{w}(E)$ for each species of ion ($p = 0.038$).

Application of Bonferrini's Inequality, at an overall level of significance of 0.05, does not reject the hypothesis $\bar{w}(E)_{C^{6+}} = \bar{w}(E)_{Ne^{10+}}$ or the hypothesis $\bar{w}(E)_{Ne^{10+}} = \bar{w}(E)_{Ar^{18+}}$ but does reject the hypothesis $\bar{w}(E)_{C^{6+}} = \bar{w}(E)_{Ar^{18+}}$.

3. Analysis for Location Effect By Two Way Classification

In this analysis only selected data from the original reference may be analyzed. The data for C^{6+} ions are excluded since they were obtained at one position. One set of data were obtained for Ne^{10+} ions (Experiment 1) and two sets of data obtained for Ar^{18+} ions (Experiments 2 and 3) - all at five locations. (One Ar^{18+} data point is excluded.) Table 3 summarizes the data used.

TABLE 3
Summary of Data Used In Two Way Classification

Experiment	CHAMBER REGION					$x_{i.}$	$\bar{x}_{i.}$
	1	2	3	4	5		
1	35.9	36.3	36.9	33.7	34.7	177.5	35.50
2	36.0	35.4	34.3	33.3	33.9	172.9	34.58
3	35.1	35.7	35.3	35.4	34.4	175.9	35.18
Σx_{ij}	107.0	107.4	106.5	102.4	103.0	526.3	
$\bar{x}_{ij}$	35.67	35.80	35.50	34.13	34.33		35.09

$$\Sigma x_{ij}^2 = 18480.75$$

$$N=15$$

$$r=3^*$$

$$c=5^*$$

TABLE 4
Analysis of Variance Table - Two Way Classification

SOURCE	SUM OF SQUARES	df	MEAN SQUARE	F
Row (Experiment)	2.1813	2	1.0906	1.77
Column (Region)	7.5127	4	1.8782	3.04
Residual	4.9433	8	0.6197	
Total	14.6367	14		

* r = No Rows, c = No Columns

A Fisher Test of the hypothesis that the column means are equal (i.e., no difference between locations) is not rejected at a level of significance of 0.05 ($p = 0.075$). Thus the data do not support the hypothesis that the values of $\bar{w}(E)$ differ as a function of location in the ionization chamber.

4. Conclusion

Analysis of the data by a one way classification suggest that there may be a difference between $\bar{w}(E)$ values for different ions at the 5 percent level of significance. The hypothesis that the values for C^{6+} ions (36.3 ± 1.1 ev) and Ar^{18+} ions (34.8 ± 0.9 ev) are equal is rejected.

The one way analysis given here suggests slightly different values of the mean values of $\bar{w}(E)$ and larger estimates of error on the means than presented in the original paper:

TABLE 5
Summary

ION	THIS PAPER	ORIGINAL
C^{6+} ions	36.3 ± 1.1 ev	36.4 ± 0.6 ev
Ne^{10+} ions	35.5 ± 1.3 ev	35.4 ± 0.8 ev
Ar^{18+} ions	34.8 ± 0.9 ev	34.7 ± 0.5 ev

The two way analysis confirms the conclusion of the original paper that there is no location effect at the 5 percent level of significance.

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