# *Electrical Conductivity of δ-Irradiated and Chemically Oxidized Wool*

## INTRODUCTION

It is well known that static charges that build up on textile materials cause a variety of trouble in the textile industry.[1–3] The limiting conditions for high static charges and hence susceptibility to trouble in use has been shown to depend on the resistance of the material. Law resistance materials will rarely give trouble, higher resistance materials will give trouble more often, and the very high resistance synthetic fibers will give the most trouble. Indeed, moisture content, moisture distribution, ion concentration, chain length, ash, density, and species are the most important factors influencing the dc resistance of textile fibers.[1–6] However, in recent years, physical and/or chemical modifications of the native wool fibers used to impart new or improved properties have become major factors in wool utilization. A new approach to modifications of the properties of wool is to expose the fibers to ionizing radiation.[7–12] In fact, a detailed study on the effect of these modifications brought about by $\gamma$ radiation and chemically oxidizing agents on its electrical conductivity has not yet been fully explored. With that in mind, present study is undertaken to investigate the effect of $\gamma$ irradiation and chemical oxidation on the electrical conductivity of wool fibers.

## EXPERIMENTAL

Wool fibers from four breeds of sheep were analyzed for their intrensic ash content. The methods of Fincham[13] for scouring and of ASTM[14] for ashing the samples were used. The fiber diameter was measured by the air flow method[15] and the moisture content was measured by the gravimetric method.[15] The samples were irradiated at room temperature in a $^{60}Co$ $\gamma$-radiation cell. The samples were oxidized by soaking in an aqueous solution of $5N$ $H_2O_2$ with pH 5 and g for different periods.

The conductivity measurements were carried out on the sample using a dc electrometer of type TR-1501 Orion-K.T.V., Budapest. A Pyrex sample holder was used. The conductivity cell with the specimen inside could be evacuated well. The samples used in the measurements were pressed into cylindrical pellets at a pressure of about 200 kg/cm$^2$. This pressure was chosen since the electrical conductivity was independent of load.

## RESULTS AND DISCUSSION

Measurements of electrical conductivity $\sigma$ were carried out on samples of wool powder with particle size diameters ranging between 0.053 and 0.297 mm in the form of compressed discks. Values of $\sigma$ were measured at different temperatures from 423 K down to 300 K in vacuum ($10^{-2}$ mm Hg).

The variation of log $\sigma$ of various wools with the reciprocal of the absolute temperature ($1/T$) is represented in Figure 1. Since there is a positive temperature coefficient of electrical conductivity ($d\sigma/dT$) for each curve, all the investigated specimens thus have a semiconducting character in the investigated temperature range.

The conductivity varies exponentially with the absolute temperature according to the well known relation[16]

$$\sigma = \sigma_0 e^{-\Delta E/2kT}$$

The activation energy $\Delta E$ was calculated from this linear relationship.

The relatively slight response of $\sigma$ with temperature variation involves $\Delta E$ values which can be interpreted by a simple single band model in most specimens. The $\Delta E$ values are assumed to correspond to the activation energies of defect mobilities.

A comparison between values of log$\sigma$ and $\Delta E$ for four varieties of wool, and the mean diameter, the moisture content, and the intrensic ash content of the fiber material was held. Table I gives the measured values. It could be noted from Table I that the electrical conductivity increases, whereas the activation energy decreases with increases in the diameter, moisture content, and the intrensic ash content of wool samples (except for Barki wool).

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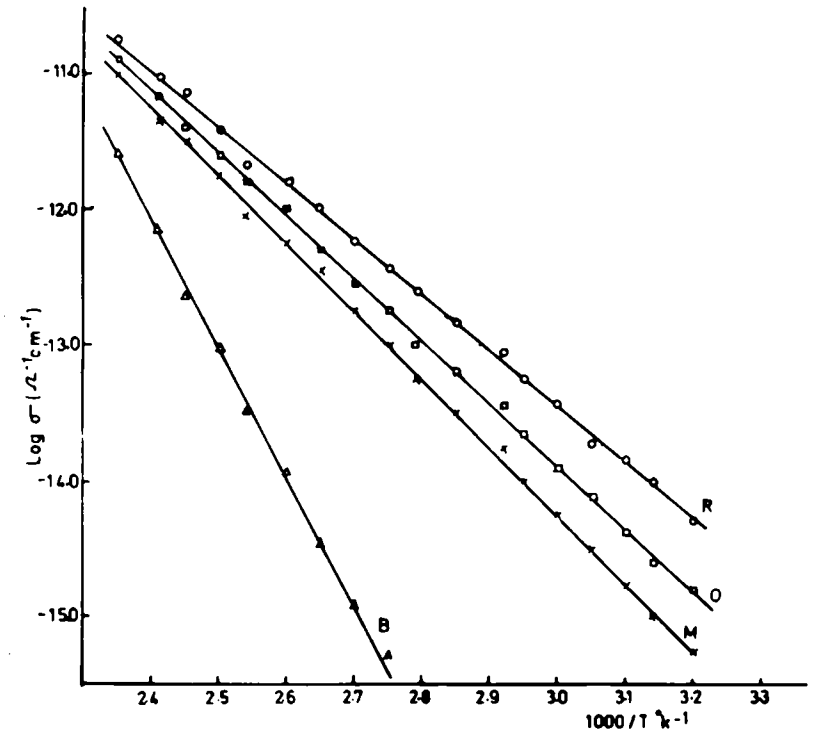


Fig. 1. Variation of conductivity of wool with temperature. R (Rahmani), O (Osimi), M (Merino), B (Barki) wool.

Samples of Merino and Rahmani wools were exposed in an atmosphere of air at room temperature to different $\gamma$ doses ranging from $1.2 \times 10^6$ to $1.1 \times 10^8$ rad. The electrical conductivities were then measured at different temperatures. The variation of log $\sigma$ (Merino wool as an example) with the reciprocal of $T$ is represented graphically in Figure 2. The variation of log $\sigma_{40}$ and $\Delta E$ with $\gamma$ doses is represented in Figures 3 and 4, respectively. It is evident that log $\sigma$ increases while $\Delta E$ decreases as the dose increases up to $1.157 \times 10^7$ rad for Rahmani wool and to $5 \times 10$ rad for Merino wool. Irradiation of the samples with doses higher than $1.157 \times 10^7$ rad for Rahmani wool and $5 \times 10^7$ for Merino wool causes rapid decrease in log $\sigma$ and increase in $\Delta E$. The sharp increase of log $\sigma$ with doses could be attributed to the increase of the number and mobility of charge carriers present. These charge carriers are created as a result of the ionizing effects of $\gamma$ radiolysis which provides mobile charges capable of conduction. The subsequent decrease in the values of the electrical conductivity at higher energy levels of $\gamma$ doses $>10^7$ rad may be considered to be a result of the association with irradiation damage and the formation of color centers (impurity centers) caused by the creation of trapping centers and/or rearrangement in the fiber structure.

TABLE I
Relationship between log $\sigma_{40}$ of Wool and Some of Its Characteristics

| log | $\sigma_{40}$ | $\delta E$ eV | Ash content, % | Mean diameter $\mu$m | Moisture content, % |
|---|---|---|---|---|---|
| Rahmani | −11.25 | 0.15 | 2.180 | 31.40 | 12.03 |
| Osimi | −11.80 | 0.20 | 0.820 | 31.03 | 8.75 |
| Barki | −13.20 | 0.44 | 0.624 | 26.40 | 7.86 |
| Merino | −12.52 | 0.29 | 0.450 | 20.82 | 6.45 |

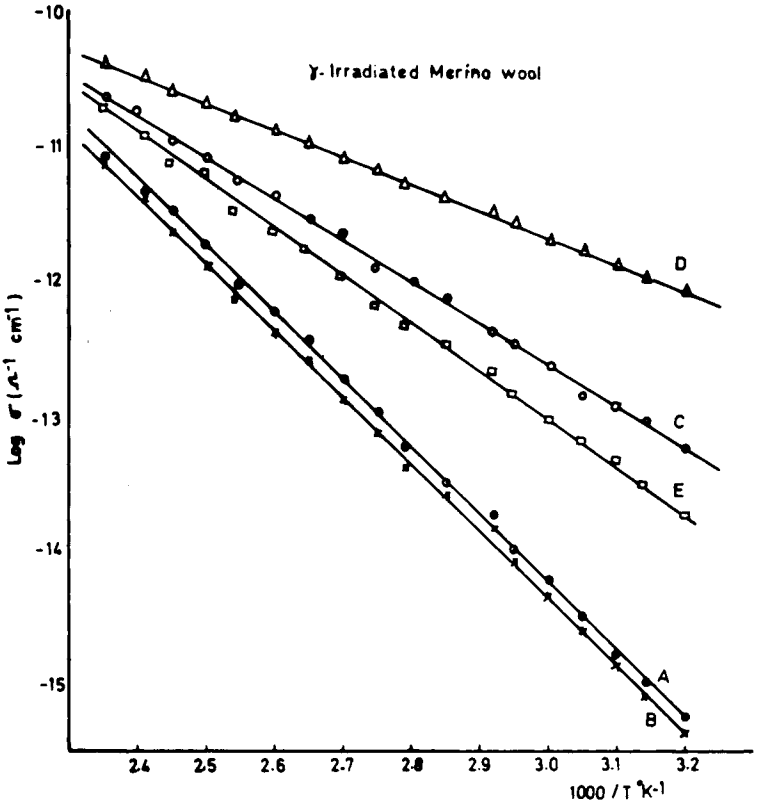


Fig. 2. Variation of conductivity of $\gamma$-irradiated wool with temperature. (A) before irradiation; (B) $1.206 \times 10^6$ rad; (C) $31.157 \times 10^7$ rad; (D) $0.506 \times 10^8$ rad.

The variation of log $\sigma$ with the reciprocal of temperature for the oxidized samples (of Merino wool for an example) is represented in Figure 5. The variation of log $\sigma_{100}$ "measured at 100°C" and $\Delta E$ with the time of oxidation is shown in Figures 6 and 7, respectively. It appears from Figure 6 that the treatment of wool with $5N$ $H_2O_2$ for 3 hr results in an appreciable increase in its electrical conductivity, while longer treatments show a sharp decrease. Figure 6 also indicates that at any given

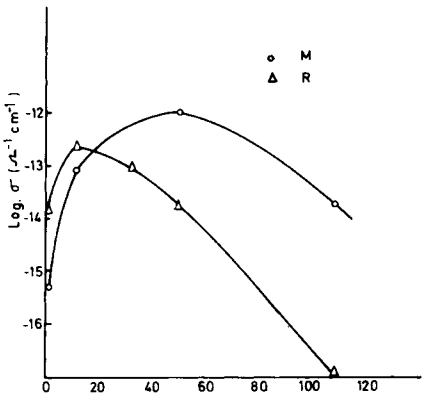


Fig. 3. Variation of conductivity of wool with $\gamma$ doses (doses in rad $\times 10^6$).

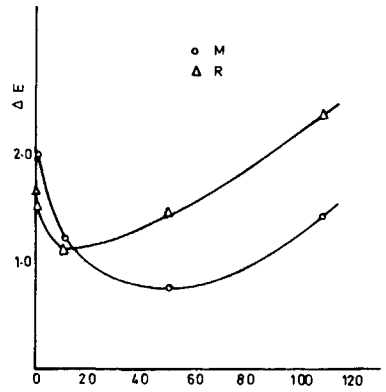


Fig. 4. Variation of the activation energy with $\gamma$ doses (doses in rad $\times 10^6$).

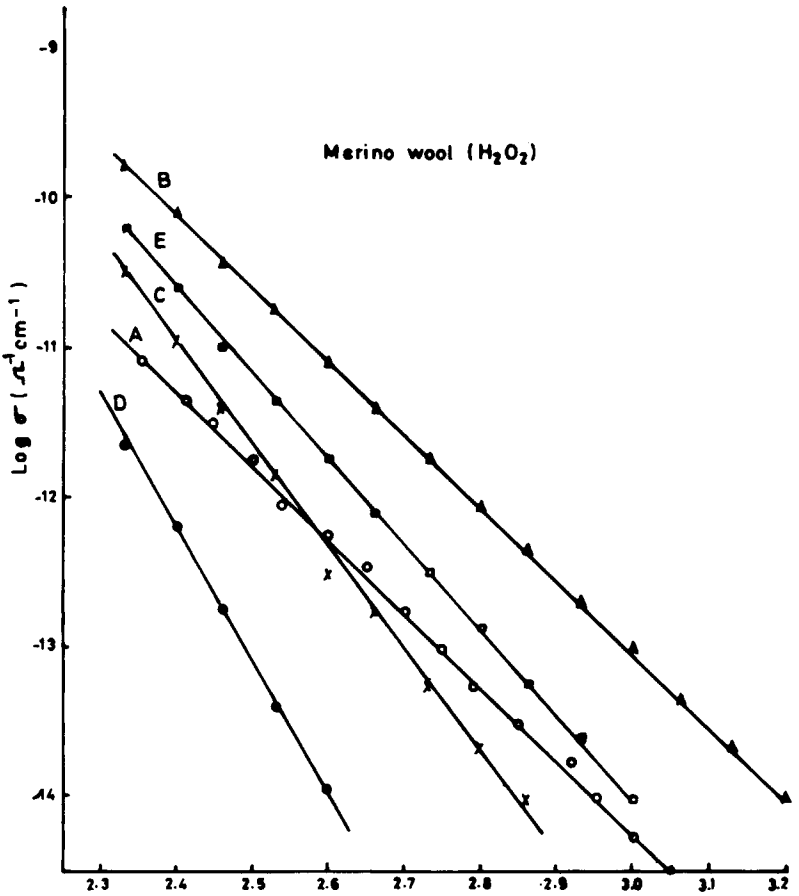


Fig. 5. Variation of conductivity of oxidized wool with temperature. (A) Untreated, (B) 3 hr, (C) 24 hr, (D) 48 hr, (E) 48 hr (pH 9).

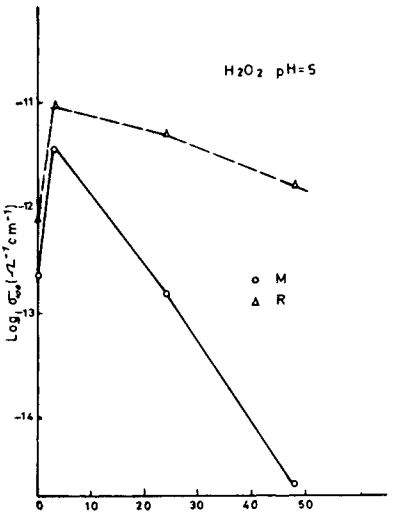


Fig. 6. Variation of conductivity of wool with time of oxidation (time in hours).

temperature, the electrical conductivity of the sample treated with $H_2O_2$ of pH 5 is always higher than that of the sample treated with the same solution but with pH 9.

Figure 7 indicates that treatment of wool with $H_2O_2$ causes an initial decrease in its activation energy, while longer treatments show considerable increase. It appears from the above-mentioned results that the mechanism of reaction is the same for the two varieties of wool, but the rate of change is different. The obtained results are in good agreement with the conclusion of Satlow[17] who claims that mild oxidation treatments of wool carpets with aqueous $H_2O_2$ at room temperature decreases electrostatic charge buildup on the material without chemically modifying the fiber to any significant extent. The reduced chargability is attributed to an increase in the hydrophilicity of the cuticle which permits conduction of the charge to the cortex.

It seems very interesting to mention here that the effect of chemical oxidation on the electrical properties of wool is similar to those of $\gamma$ radiation. This result is in good agreement with the results obtained by Kirby and Rutherford[18] who stated that the effect of hydrogen peroxide is more nearly like that of nuclear radiation.

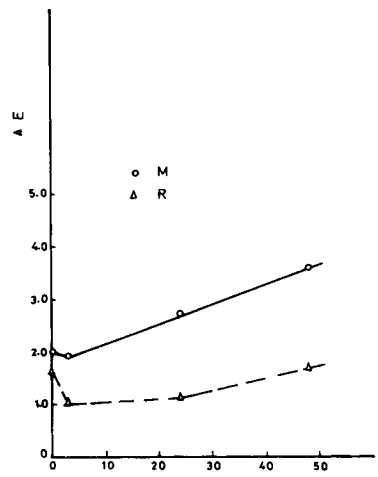


Fig. 7. Variation of activation energy with time of oxidation (time in hours).

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