Conductance of Activated Carbon

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ABSTRACT

The conductance of activated carbon and activated carbon impregnated with copper has been measured. The results suggested that both materials were semiconductors with increasing conductance as copper content was increased.

INTRODUCTION

Structurally, activated carbon can be regarded as an aggregation of disordered carbon particles separated by pores. Each of these particles consists of several layers of graphite planes. The ringed structure at the edges of these planes is often heterocyclic or may be bonded to organic functional groups. Measurements of the conductance of activated carbon yielded a value in the order of $10^{-1}$ (ohm-cm)$^{-1}$ (Badri, et al., 1984). Based on the classification of conducting material (Cowan and Wiygal, 1986) activated carbon can thus be considered as a semiconductor.

For a doped semiconductor, the temperature dependent of its conductance, $\sigma$, is given as

$$\sigma = A_1 \exp (-E_i/2kT) + A_\sigma \exp (-E_g/2kT)$$

where $E_i$ is the ionization energy of the impurities in the sample, $E_g$ is the band gap of the intrinsic material, $k$ is the Boltzmann constant, $A_1$ and $A_\sigma$ are preexponential factors which vary slightly with temperature, T. A plot of $\ln \sigma$ against $1/T$ would yield two intersecting straight lines. The high-temperature slope would give $E_i$ while the low-temperature slope would give $E_g$.

When a piece of activated carbon is brought into contact with an electrolyte, the contact is established both at the external surface as well as at the wall of the pores. Thus when activated carbon is used as a cathode in an electrolytic cell, deposition of metal would occur not only on the external surface but also on the internal surface, i.e. on the wall of the pores. The resulting product would be a metal impregnated activated carbon, similar to supported metal catalysts of silica and alumina. The subject of the present study is to find out how the impregnated metal would affect the conductance of activated carbon.

MATERIALS AND METHODS

Large pieces of activated carbon were prepared by a method described earlier (British Patent, 1983). Fairly large pieces were chosen and ground into discs of approximately 10.2mm in diameter and 1.5mm in thickness. The discs were soaked in 1M HCl for one week followed by another week of continuous washing with dis-
tilled water in a Soxhlet apparatus. After washing they were dried at 110°C for 24 hours.

For the deposition of metal, each disc was clamped tightly between a copper disc of similar diameter and a strong plastic pipe standing in a small plastic cup (Fig. 1). The interior of the pipe was packed with foam rubber to act as a wick for the electrolyte to rise from the cup to the underside of the carbon disc. Solution of 1M CuSO₄ and a copper anode were used for electrolysis. Deposition was continued for different time intervals for different discs to vary the amount of copper deposited. When deposition was complete, the disc was washed again in a Soxhlet apparatus for two days. It was then dried in a vacuum oven at 70°C for three hours before use.

The conductance measurements of each carbon disc were made by placing the sample in between two circular platinum electrodes in a vacuum chamber equipped with an internal heating facility and connected to a Wyne-Kerr Autobalance Universal Conductivity Bridge B642. The first set of readings was recorded while the temperature of the sample was raised stepwise from 30°C to a maximum of 394°C. Next, some values were obtained during subsequent cooling and reheating of the sample. For the purpose of calculation, only the first set of readings was used.

After conductance measurements were done, the disc was burnt in air in a clean crucible and the ash was weighed and dissolved in 6M HCl of analytical grade. Copper content was determined by using a standard procedure for atomic absorption spectrophotometry.

### RESULTS

The amount of copper present in each carbon disc is given in Table 1. For the untreated disc, this amount was only a very small fraction of the total inorganic ash (which was about 0.04% by weight of the disc).

The conductance of the metal-impregnated samples at room temperature was found to increase with copper content. The relationship seems to be exponential, as shown in Fig. 2.

### TABLE 1

<table>
<thead>
<tr>
<th>Sample</th>
<th>% Cu (by weight)</th>
<th>30°C (\times 10^6) (ohm-cm)</th>
<th>(E_g) (eV)</th>
<th>(E_f) (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0032</td>
<td>1.67</td>
<td>0.91 +/- 0.01</td>
<td>0.475 +/- 0.003</td>
</tr>
<tr>
<td>2</td>
<td>4.530</td>
<td>1.23</td>
<td>0.984 +/- 0.003</td>
<td>0.542 +/- 0.005</td>
</tr>
<tr>
<td>3</td>
<td>8.760</td>
<td>2.21</td>
<td>0.893 +/- 0.009</td>
<td>0.48 +/- 0.01</td>
</tr>
<tr>
<td>4</td>
<td>8.760</td>
<td>4.27</td>
<td>0.89 +/- 0.01</td>
<td>0.52 +/- 0.06</td>
</tr>
<tr>
<td>5</td>
<td>15.12</td>
<td>27.14</td>
<td>0.875 +/- 0.005</td>
<td>0.54 +/- 0.01</td>
</tr>
</tbody>
</table>
CONDUCTANCE OF ACTIVATED CARBON

Fig. 2: Conductance of activated carbon impregnated with Cu at 30°C. S1 is the untreated sample.

All samples were found to have higher conductance at elevated temperatures. There was, however, a small difference in the values obtained at a given temperature for each sample depending on whether the measurement was taken during heating or cooling or on subsequent reheating. These differences are shown in Fig. 3 for the carbon disc containing 15.12% Cu by weight as an example.

Plots of In \( \sigma \) Vs 1/T on first heating are given in Fig. 4 for samples of various Cu content. For each sample two intersecting straight lines were obtained. From the slopes of the curves the values of \( E_1 \) and \( E_8 \) were calculated and are given in Table 1.

DISCUSSION

The increase in the conductance of activated carbon with temperature confirmed its semiconducting properties. However, the nature of the charge carriers, whether they were electrons or positive holes, has yet to be determined. Considering that activated carbon is an aggregate of disordered carbon particles, the most likely charge carriers were electrons.

The fact that the plot of In \( \sigma \) Vs 1/T for the untreated carbon gave two intersecting straight lines (Fig. 4) showed that the samples contained impurities. These impurities, amounting to about 0.04% by weight, which appeared as ash after combustion, seemed to be a reasonable value for an extrinsic semiconductor. The amount of copper present in the untreated carbon seemed to be comparable to the requirement of living plants, which is at least 6ppm (Epstein, 1972). It seems that in the low temperature region of In \( \sigma \) Vs 1/T plot, the impurities were responsible for the semiconducting behaviour of the untreated carbon by acting as donors, supplying the electrons to the conduction band lying at about 0.5 eV above the impurity level. If the high temperature region of the In \( \sigma \) plot could be associated with intrinsic conductivity of active carbon, then the electrons
from the valence band were thermally excited to the conduction band across a band gap of about 0.9 eV. This value for \( E_g \) is much bigger than that given for graphite, but comparable to those of silicon and germanium, being 1.09 eV and 0.66 eV respectively.

The difference in the conductance of pre-heated and fresh samples was probably due to the increase in the number of carriers as a result of the decomposition of the functional groups or the increase in the mobility of the carriers due to sintering. Sintering is known to occur in carbon heated at higher temperatures (Snoeyink and Weber, 1972) resulting in the bridging of the pores between the carbon particles. This would facilitate the flow of electrons, leading to the increase in the conductance as observed. On the other hand, the decomposition of the functional groups would introduce extra \( \text{C} = \text{C} \) double bonds in the graphite layers. In this way, the number of electrons in the \( \pi \)-system would be increased resulting in the increase of the electrons in the conduction band.

The fact that the samples impregnated with copper also showed two intersecting lines in their \( \ln \sigma \) vs \( 1/T \) plots, with similar \( E_g \) and \( E_f \), indicates that the untreated carbon did not lose its semiconducting properties even after impregnation. The general increase in the conductance as the amount of copper was increased was probably due to the bridging of the gaps between the particles by copper crystals. The effect of bridging was to reduce the ohmic resistance of activated carbon due to the pores. In this way, the higher the degree of impregnation the more extensive the bridging would be. The exponential increase in the conductance with respect to copper content was perhaps due to the closing of the adjacent pores as well when bridging occurred across a particular pore.

The activation energies were about the same for all the samples including the untreated carbon. This seems to imply that copper deposited on the wall of the pores did not diffuse into the lattice in any significant quantity and the original amount of impurities also remained the same. This information would be useful in considering the material as a high conducting component in gadgeteries with semi-conducting properties.

**REFERENCES**


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