MOISTURE-TEMPERATURE DEGRADATION
IN MODULE ENCAPSULANTS

## JET PROPULSION LABORATORY

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The General Problem of Moisture
in Photovoltaic Encapsulants

- **Water transport**
  - **Rain, snow**
  - **Condensation, dew**
  - **Changes in water vapor pressure**

- **Effects of water in photovoltaic modules**
  - **Swelling of polymers and gaskets**
  - **Delamination of encapsulant**
  - **Galvanic (contact) corrosion**
  - **Electrochemical (leakage current) corrosion**
  - **Plays an active role in**
    - **Photo degradation**
    - **Voltage breakdown**

General Research Approach

- **For a given degradation mechanism, establish module performance loss versus level of accumulated degradation**

- **Establish dependence of rate of degradation reaction on moisture and temperature level in module**

- **Establish moisture and temperature level in module versus time in field environment and module construction**
  - **Sealed module**
  - **Partially sealed module**
  - **Unsealed module**

## Power Output Reduction vs Accumulated Unit Charge Transfer
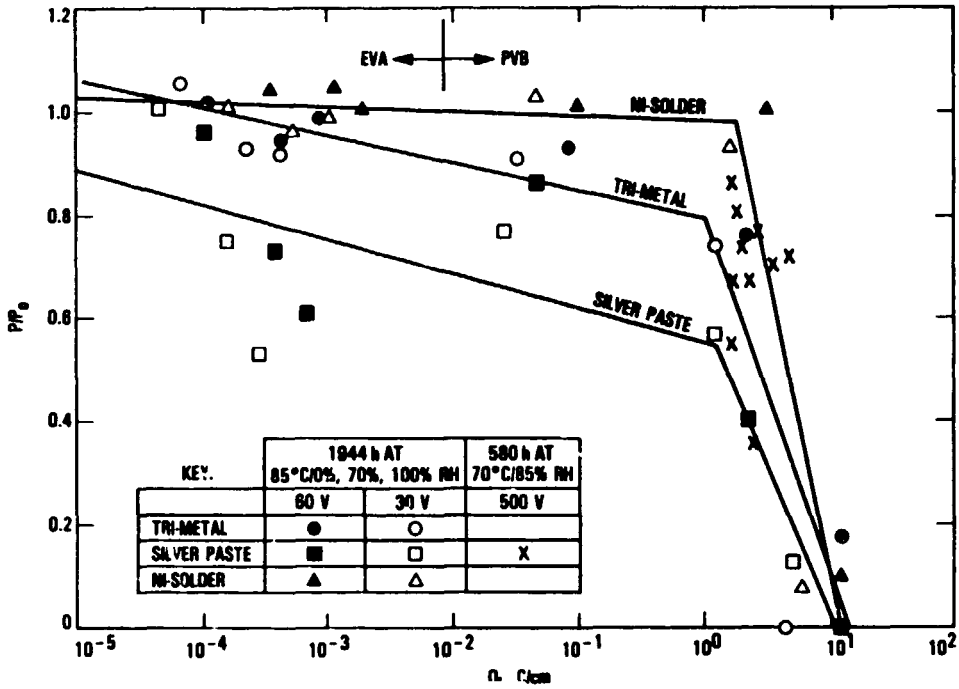
Electrochemical Corrosion: Analysis of Leakage Current

- **Leakage Current**
  - **Leakage current (rate of transfer of charge) is responsible for electrochemical corrosion**
  - **Leakage current magnitude is determined by**
    - **Applied (or generated) voltage V**
    - **Insulation (encapsulant) surface and volume conductivities**
- **Encapsulant conductivity**
  - **Insulation conductivity increases with increasing**
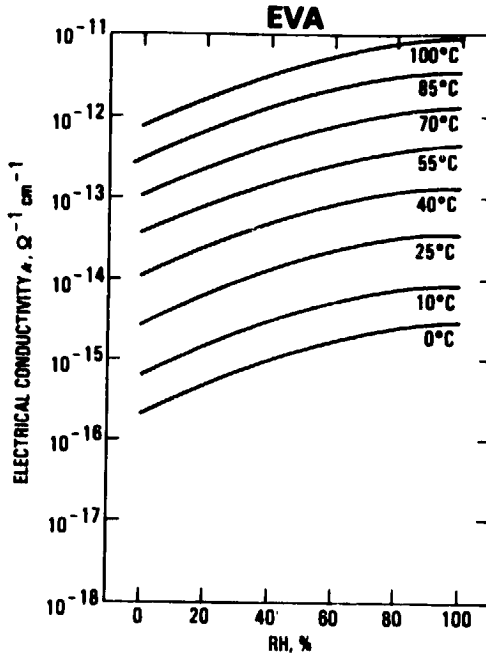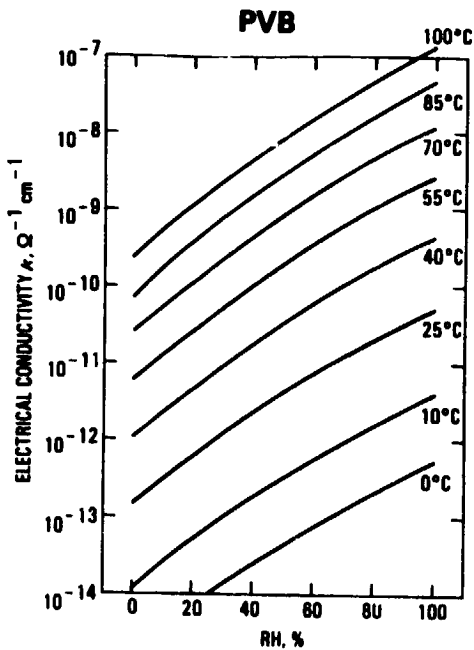   - **Temperature**
    - **Moisture content**

Experimental Determination of the Electrical Conductivity of PVB and EVA
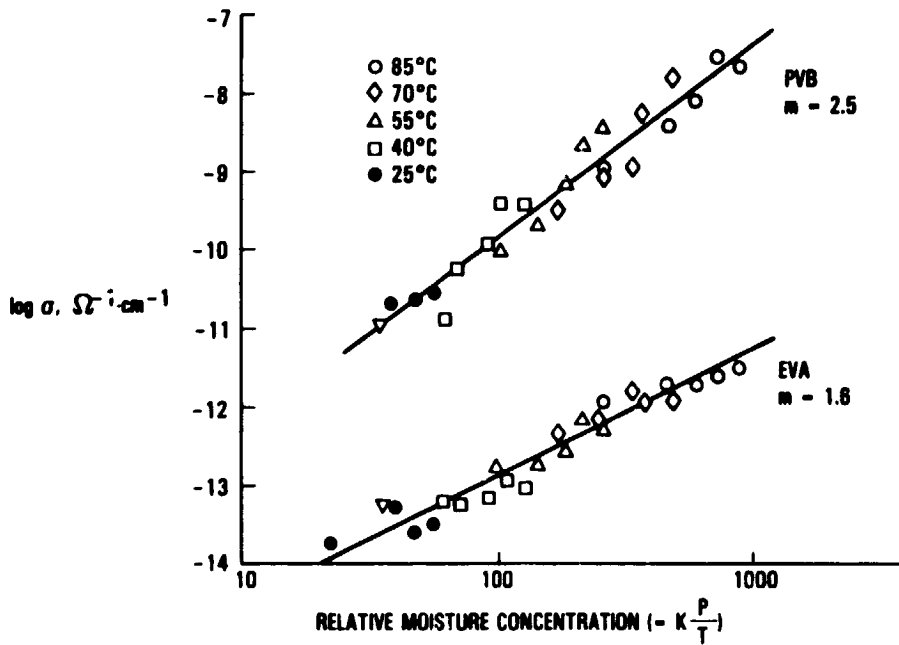
- **Experimental setup:**
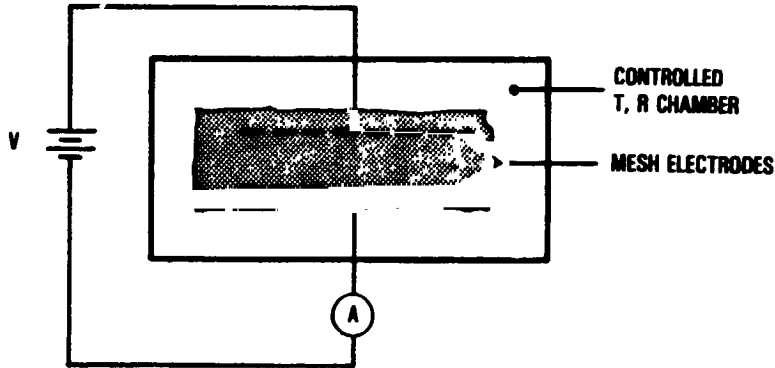
- **Equilibrium values measured by Professor J. Orehotsky**
- **Experimental equilibrium values were processed, yielding sets of "best-fit" data curves**

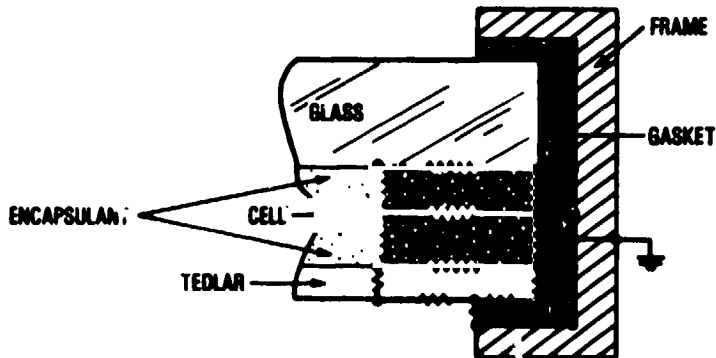## Electrical Conductivity of PVB and EVA

Bulk Conductivity vs Moisture Concentration
(From Orehotsky Data and Ideal Gas Law)

Module Performance Analysis

- **Life prediction requires calculation of charge transfer in a real module**
  - **Through the bulk pottant**
  - **Along material interfaces**
 - **On free surfaces**

- **Leakage current path modelling**

Research Questions About Module Conductivity

- Over what ranges of temperature and relative humidity do the various conductivities dominate overall module conductivity?

- In what ways do the various forms of water in polymers contribute to overall module conductivity?
  - Bound water
  - Free water
  - Clustered water

- Does exposure to liquid water result in same measured conductivity values as exposure to saturated water vapor?

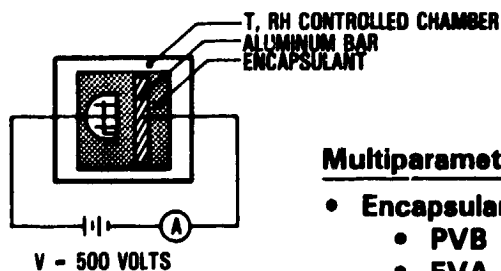## General Dependencies Involving Insulation Electrical Conductivities

- Surface conductivity values are strongly affected by contaminants

- Surface conductivity responds rapidly to changes in relative humidity and surface-water films
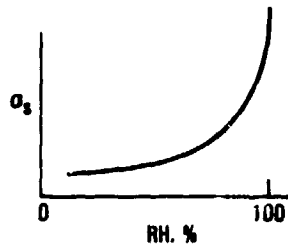
- Volume conductivity responds rapidly to changes in temperature, less rapidly to changes in relative humidity

- $\sigma_v = Ae^{-E/T}$ (ASTM D257-78)

- Generally, $\sigma_s > \sigma_v$

Experiments to Determine Module Equilibrium Leakage Current Levels and Response to Parameter Variation
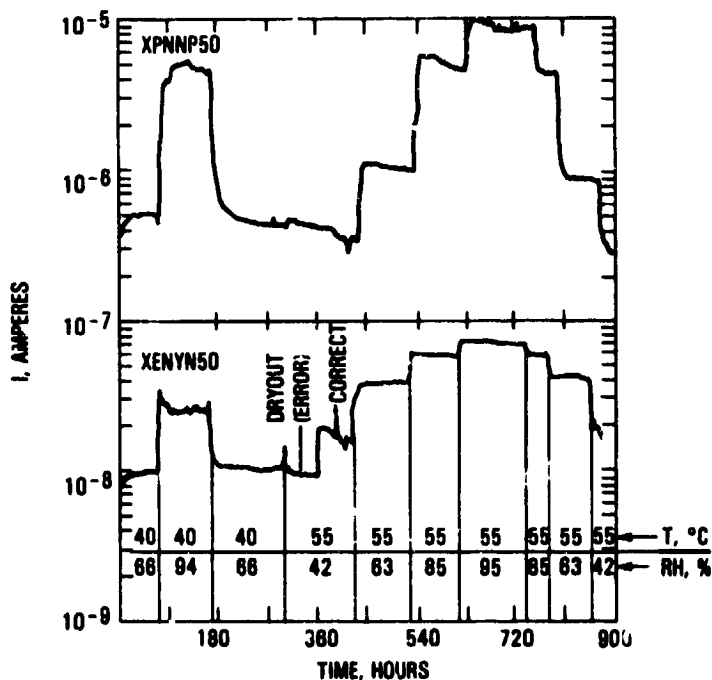
Test setup

T, RH CONTROLLED CHAMBER
ALUMINUM BAR
ENCAPSULANT
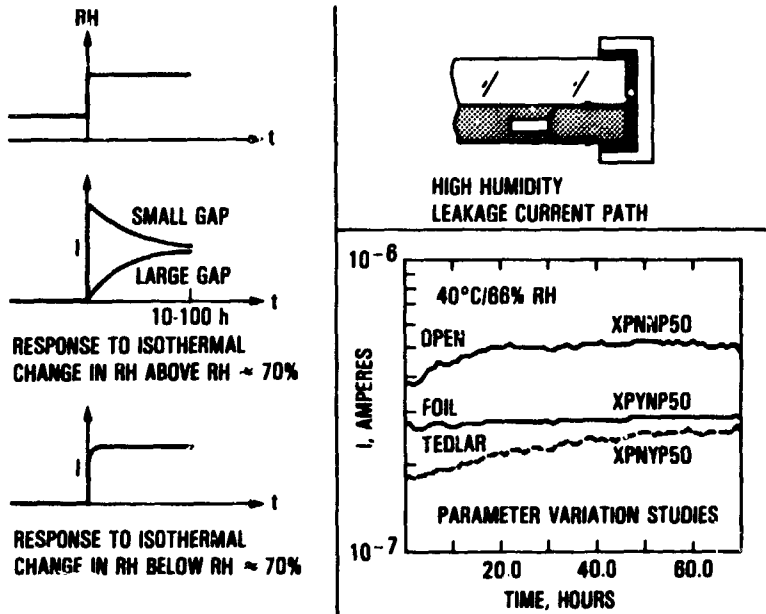
V - 500 VOLTS

Multiparameter testing

- Encapsulants
  - PVB
  - EVA
- Polarity
  - Positive
  - Negative
- Electrode spacing
- Rear-surface barriers
  - Polymers
  - Metal foils
  - None
- Cell metallizations

**Test sequence**

T, °C	RH, %					
40	66	94				
55	42	63	85	95		
70	<10	50	71	85	95	
85	<10	30	50	70	85	95

Current vs Time

Some General Observations

RESPONSE TO ISOTHERMAL
CHANGE IN RH ABOVE RH ≈ 70%

RESPONSE TO ISOTHERMAL
CHANGE IN RH BELOW RH ≈ 70%

HIGH HUMIDITY
LEAKAGE CURRENT PATH

40°C/66% RH

OPEN   XPNNP50
FOIL   XPYNP50
TEDLAR   XPNYP50

PARAMETER VARIATION STUDIES

Leakage Current Sensitivity to Relative Humidity at 40°C and 55°C: PVB, Positive Polarity, 50-Mil Gap

OPEN, 55°C
OPEN, 40°C
TEDLAR, 55°C
TEDLAR, 40°C
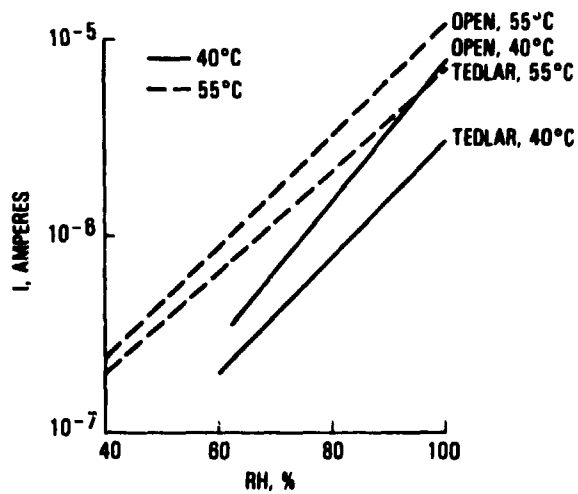
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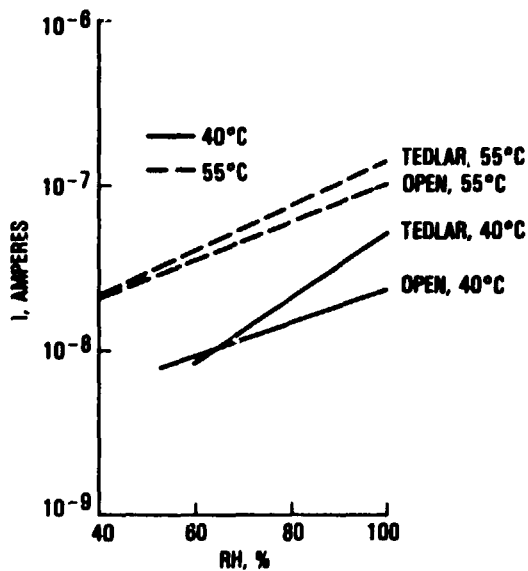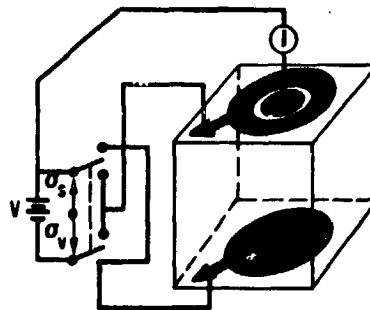

Conclusion

- Because of the importance of bulk, interfacial, and free-surface conductivities, additional experiments are necessary to separate the relative contributions of these to overall module conductivity

Direct Conductivity Measurements
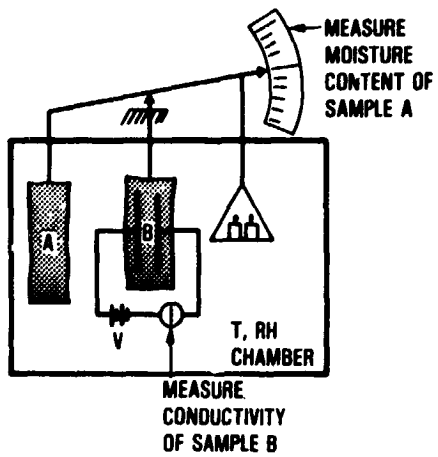
- **Cahn balance sorption test**
  - **c = S(T) RH**
  - $\sigma = \sigma(V; T, c (T, RH))$
    $= \sigma(V; T, RH)$

- **Guarded electrode measurements**
  - **Surface and volume conductivities**
    - **PVB**
    - **EVA**
  - **Interfacial conductivity**
    - **Glass/polymer**
    - **Polymer/Tedlar**