ministerie van verkeer en waterstaat

koninklijk nederlands meteorologisch instituut

the KNMI Lyman-alpha hygrometer

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KNMI

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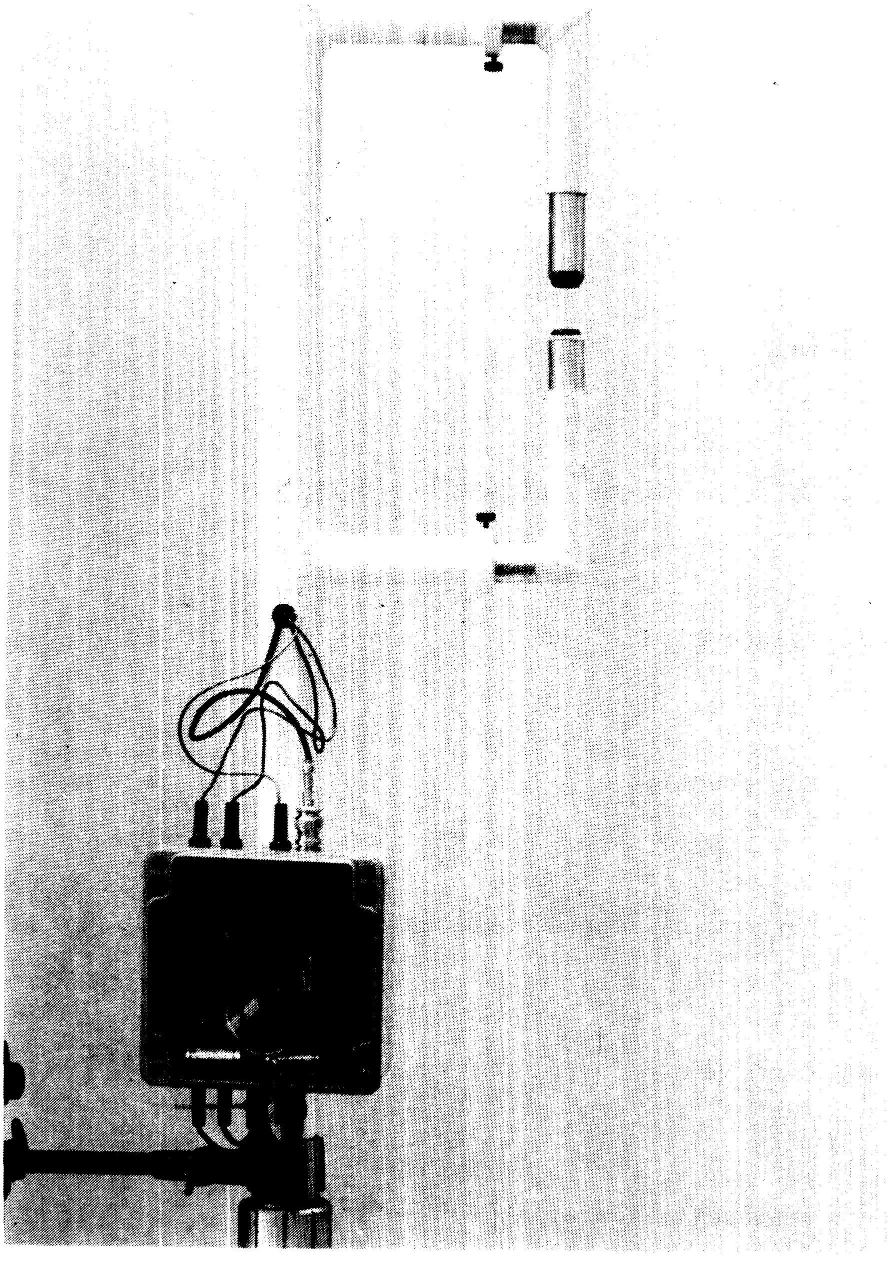

Plate 1 The KNMI Ly-α hygrometer. The cover of the box housing the electronics has been removed.

1. Introduction

The purpose of this report is to give a practical guide for working with the Ly-α hygrometer built by the KNMI (see Plate 1). For a better understanding of the instrument, some background information on humidity measurement by absorption of Ly-α radiation has been included. The comments and experiences given in this report are specific to the type of Ly-α built by us. It should be kept in mind that other types exist, with characteristics different from our Ly-α.

2. Operating principle

The radiation of the emission line of atomic hydrogen at 121.6 nm, the so-called Lyman alpha line, is strongly absorbed by water vapor. Also molecular oxygen absorbs strongly in this spectral region, but happens to have a pronounced dip in its absorption spectrum near 121.6 nm, which makes that the water vapor absorption is by far dominant there. To give an idea of the absorption strength, at an absolute humidity of 10 gm^{-3}, 50 per cent of the Ly-α radiation is absorbed over a path of 0.14 cm. This amount of absorption makes that the useful length of the transmission path is limited to a few cm at most. The Ly-α hygrometer is thus capable of measuring the humidity of a small volume of air; together with the fast time response of the instrument (in the order of 1 ms), it is ideally suited for detecting fast humidity fluctuations in the atmosphere.

If the radiation source was to emit the Ly-α line only, then the absorption would obey Beer's exponential law. In practice, however, the source emits a spectrum of lines, in which the Ly-α line is the most important one. The absorption curve therefore reflects a superposition of several exponential dependencies and consequently is curved on a semi-log plot instead of a straight line. This is a disadvantage for the user because signals of instruments that show a linear response are easier to process. To make things even worse, it has been observed that the absorption curve is not stable over long periods of time, which necessitates a periodical check on the instrument's calibration. Some more words on this topic are devoted to in the next section. Other causes of instrumental drift are changes of the transmission of the windows of the source tube and the detection tube, and drift of the radiation intensity output of the source. Window transmission may change because of dirt, grease etc. In normal operation, the window transmission deteriorates up to 2% per hour. These effects can be compensated for by baselining the instrument against another (slow response) hygrometer.

The source is a low pressure hollow cathode discharge tube. It is filled with approximately 3 torr H_2. The detector tube is a nitrix oxide ion chamber filled with 18 torr gas. Nitrix oxide has an ionization threshold of 135 nm. Both tubes have magnesium fluoride windows. Magnesium fluoride is one of the few materials which transmits the Ly-α line. Its cutoff wavelength is 115 nm. No other radiation filtering than that provided by the ion chamber and windows is done, none is virtually possible either. The dimensions of the tubes are: length approximately 40 mm and diameter 16 mm.

3. Calibration

Figure 1 shows two examples of the calibration curve of the Ly-α hygrometer. For higher values of the product of the absolute humidity (ρ) and path length (x), the curve approaches to a straight line, which indicates that the absorption behaves according to the law of Beer. Considering calibration curves of one and the same Ly-α at different stages in its life, it is found that the straight line always shows up with unchanged slope, but that the part at lower values of ρx increases its curvature with increasing age. Moreover, if one examines different, unused Ly-α's, their curved parts are found to be not coincident, while their straight portions exhibit the same slope. By shifting the curve along the horizontal axis the straight portions can be made coincident, so as to compare better the curved parts. In Fig. 1 the extreme behaviors have been drawn that I have observed so far. I noted that these curves, and curves in between (not shown in Fig. 1) can be reduced to one and the same curve by shifting along the straight portion. This means that a two-point calibration would suffice to define the whole curve, provided that one point is on the straight part and the other on the curved part. Of course, calibration of a Ly-α at several points is preferable. Calibration is advisable before and after a measuring campaign, or at least twice a year.

While preserving its shape, the calibration curve may shift horizontally in Fig. 1 by changes of the transmission of the windows and the radiation output of the source. These changes may occur in typical time intervals of one hour. They are easily compensated for by comparing the Ly-α reading to that of a nearby placed reference hygrometer. The

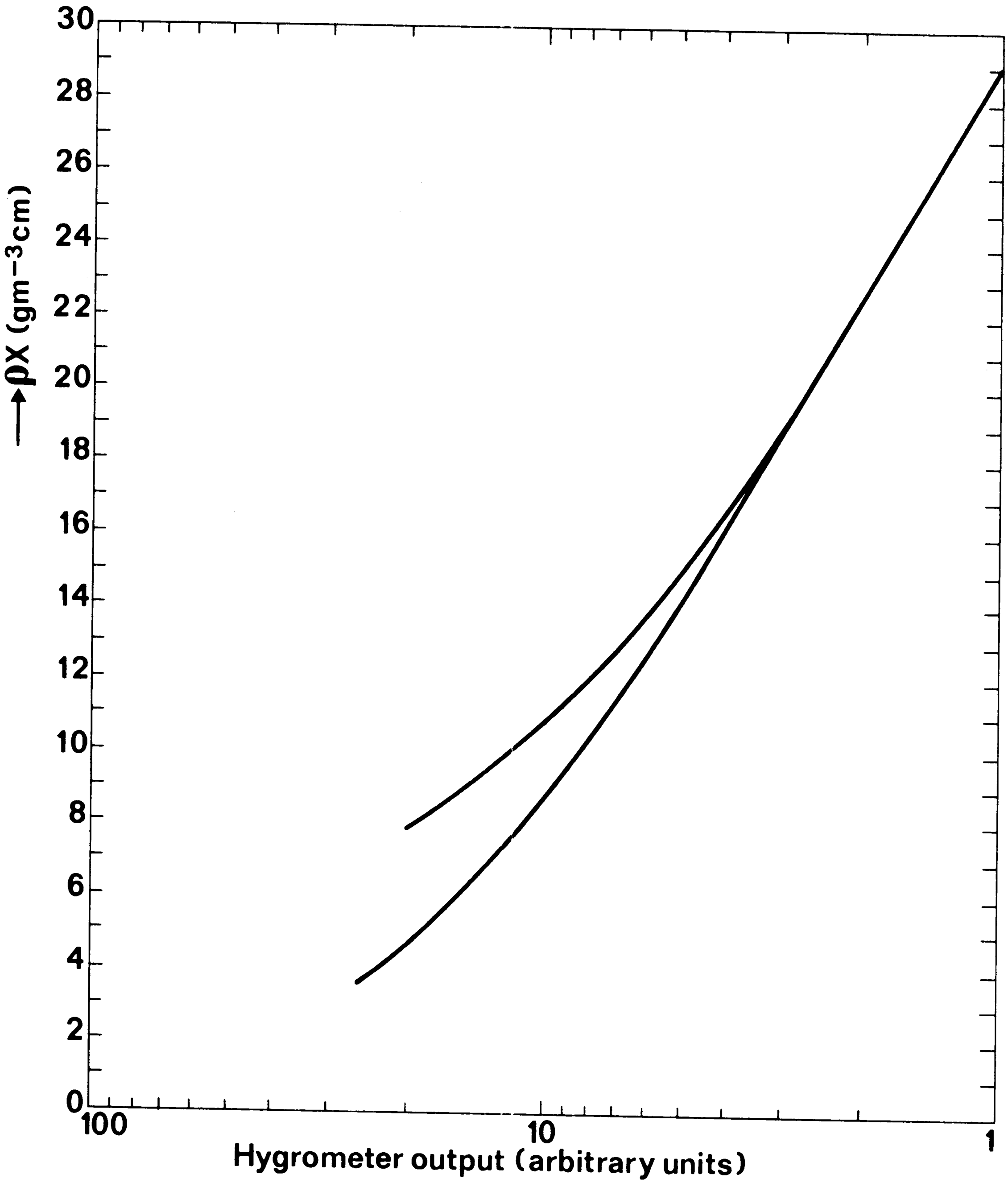

Fig. 1 Response curves. The horizontal scale has to be set by baselining the Ly-α to a reference hygrometer. The actual shape of the response curve has to be determined by calibration. It may differ from one Ly-α to another, and change during the life of a particular Ly-α.

comparison should last several minutes or more, depending on the response time of the reference hygrometer, and should be done with a frequency of at least once per hour. A fine solution is to include the reading of the reference hygrometer in the data reduction algorithm.

It will be clear from the above that the Ly-α is not to be seen as an instrument that can measure humidity in an absolute sense for long periods of time. Rather, it is used as an instrument for measuring fast humidity fluctuations. The relation between the electrical output signal of the Ly-α and the humidity fluctuations depends on the actual position on the calibration curve. This position can be influenced by the choice of the path length x. One may choose x such that ρx is on the straight part of the curve. In that case one is not sensitive to ageing, because this will not change the slope of the straight line. The disadvantage is that one has a relatively low signal. On the other hand, if x is chosen such that one is on the curved part of the calibration curve, one has the benefit of a relatively large signal but the disadvantage of being sensitive to ageing. In the latter case, it is obviously desirable to have a more frequent check on the calibration curve than in the former case.

4. Calculation of absolute humidity

A second-order polynomium provides a satisfactory fit to the calibration curve; thus we can write

$$\rho = aS^2 + bS + c, \tag{1}$$

where S is the logarithm of the normalized output signal. The normalization is arbitrary; different normalizations will give different values of a, b and c that can be interrelated in a straightforward way. A shift of the calibration curve due to change of window transmission etc. as discussed in the foregoing section, will change Eq. (1) as follows:

$$\rho = a(S - S_o)^2 + b(S - S_o) + c. \tag{2}$$

The shift S_o can be determined by baselining the Ly-α to another hygrometer.

Often, one is interested in the fluctuations of ρ rather than in its absolute value. It is then sufficient to know the value of $d\rho/dS$ at the average value of the humidity, $\overline{\rho}$. One can easily show that, for any S_o,

$$\frac{d\rho}{dS} = (D + 4a\overline{\rho})^{\frac{1}{2}} , \tag{3}$$

$$D = b^2 - 4ac. \tag{4}$$

So one can calculate the fluctuations of the absolute humidity from the fluctuations of the output signal, the average humidity as measured by a reference hygrometer, and the calibration constants a, b and c. The explicit value of the shift S_o is not needed.

5. Maintenance

A drop of the output voltage of the hygrometer, or an apparent increase of the humidity, is a sign that the windows need cleaning. Cleaning can be done by wiping the windows with a moist, soft cloth, tissue, lens paper, or Q-tip. Also alcolhol or acetone can be used as a wetting agent. In case of sticking dirt, the windows may be lightly scrubbed with a fine polishing compound, and washed thereafter. For some minutes after cleaning, the instrument may show some drift.

Occasional rain should not cause serious damage to the instrument if care is taken to keep all electrical connections dry. The magnesium fluoride windows are hardly affected by water, in contrast to lithium fluoride that has been used as a window material in the past. Nevertheless, I observed premature failure of source and detector tubes that possibly was related to rain. Not the windows were the cause of failure, but the silver chloride sealing between window and pyrex tube. Recent tubes have been provided with a different sealing that should perform better, but at the moment I have little experience with them. The normal life of the source and the detector should be several hundreds of hours of on-time. Shelf life should be indefinite.

6. Construction

a. Mechanical

The Ly-α has a simple mechanical construction shown by Fig. 2. The design criterium was to have a stable mount with little obstruction of the natural air flow. Both the source tube and the detector tube can be moved

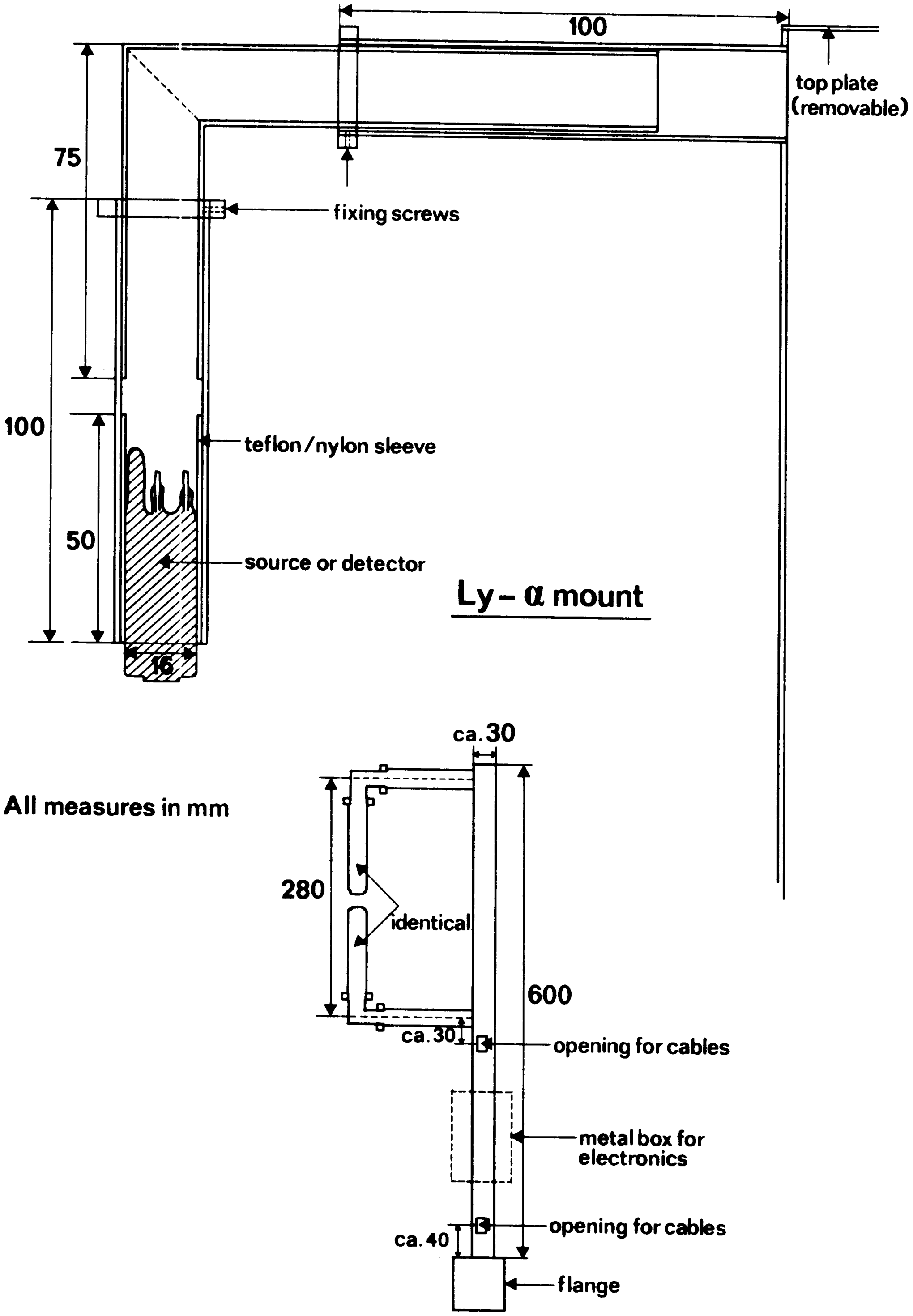

Fig. 2 Ly-α mount. The lower figure gives the over-all view, the large figure details of the mount of the source (or detector) tube. (Note: Plate 1 shows an upgraded version).

along their axes so as to change the path length, and they also can be swivelled outwards for maintenance, replacement etc. A minimum demand on the rigidity of the mount is that the path length remains constant within 0.5%. To the lower end of the P construction a little box is mounted that houses the electronics. The cable from the detector tube to the electronics should be shielded and preferably not exceed a length of 0.5 m. Flexing of the cable is to be avoided because of the high output impedance of the detector tube (typical detector currents are in the range of 10^{-8} to 10^{-10} Ampère).

b. Electronical

A schematic of the electronics is given in Fig. 3. Essential is the electrometer connected to the detector tube. It must have a high input impedance, of the order of $10^{12}\,\Omega$.
The detector tube itself should be surrounded by a shield at ground potential so as to avoid line frequency pick-up. Sufficient shielding is achieved by grounding the mount. In order to avoid leak currents at the base of the detector tube, it is advised to protect the electrical connections with silicon rubber (RTV). The source current can be varied with a potmeter on the printed circuit board; 0.1 to 1 mA is advised. Higher currents may reduce the lifetime of the tube. Close to the source tube a 100 kΩ series resistor may be mounted to avoid hf oscillations of the source current. Ignition of the gas discharge requires a voltage of at least 650 V; the operating voltage of the tube is 300-350 V.

7. Performance specifications

Resolution of fluctuations	< 0.2% of absolute humidity
Accuracy if used as an an absolute instrument	0.3 gm^{-3} if recently calibrated and baselined once per hour
Hysteresis	none
Frequency response	dc - 500 Hz (3dB roll-off point, set by electronics)
Noise (referred to output voltage)	line frequency pick-up: 10 mV_{t-t} spikes: 2.5 kHz, 50 mV_{t-t}
Warming-up time	< 1 minute
Power required	2 W. The instrument must be connected to a + and - 15 V voltage source.

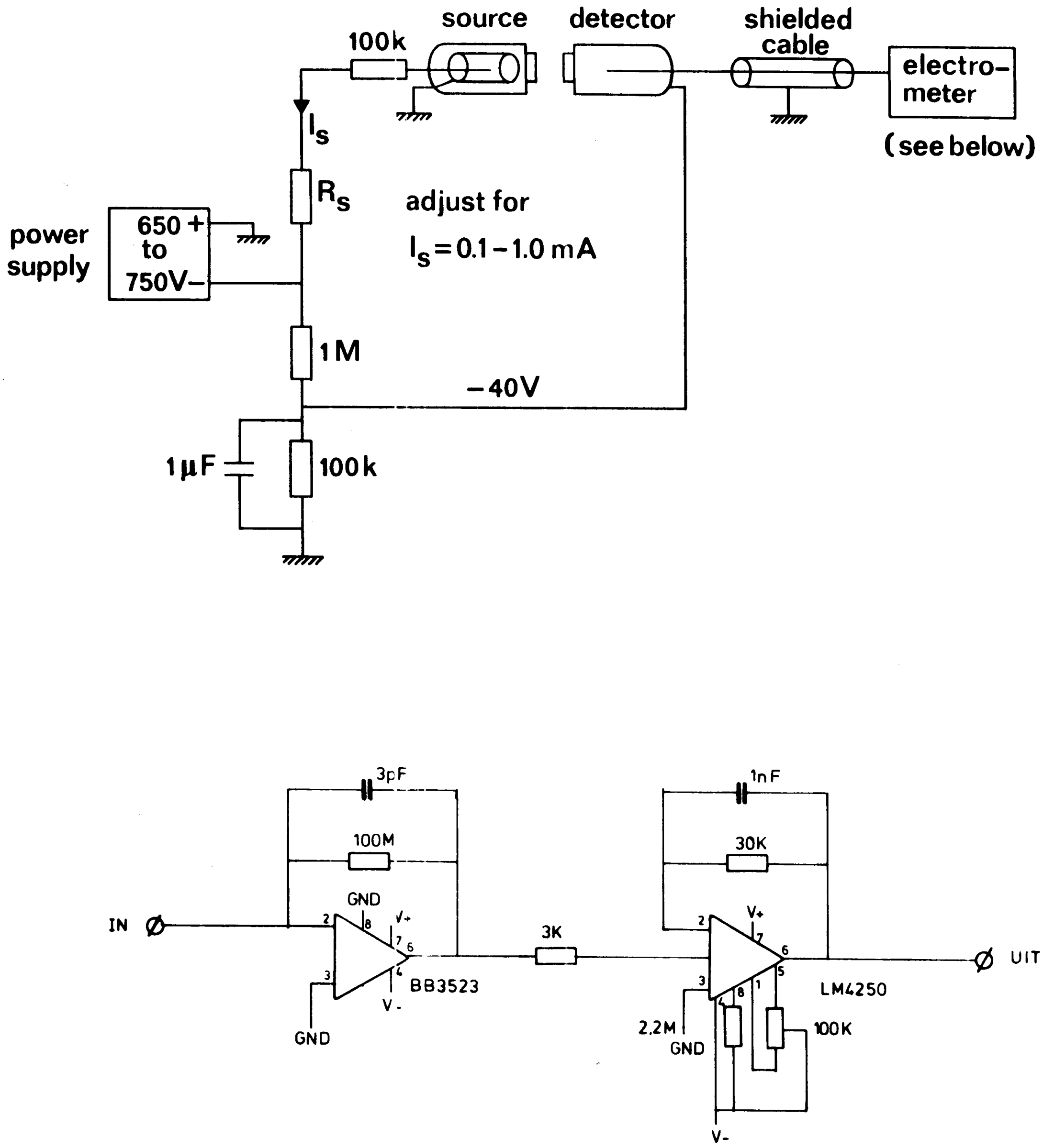

Fig. 3 Electronical scheme.

8. Parts list

Item	Manufacturer	Model	Typical price (1985)
Source	Glass Technologists 700 Holly Drive North Route 10, Annapolis, MD 21401 tel. (301)-454-2618	GT 202 M	U.S. $ 230.--
Detector	Same	GT 203 D	$ 230.--
Electrometer	Burr-Brown or Teledyne Philbrick	BB 3523 L 1035	ƒ 250,-- ƒ 350,--
Power supply	Tecnetics	9567-113	ƒ1.000,--
Resistors, Capacitors	Any good quality fabricate		

9. Commercially available Ly-α's

At the moment of this writing, I know of the following manufacturers:

- Electromagnetic Research Corporation
  5465-C Randolph Road
  Rockville, M.D. 20852
  U.S.A.
  (301)-468-0676

- Ambient Analysis Inc.
  P.O. Box 4056
  Boulder, CO 80306
  U.S.A.
  (303)-442-5305

- Campbell Scientific, Inc.
  P.O. Box 551
  Logan, Utah 84321
  (801)-753-2342

10. Literature

Buck, A.L., 1985: The Lyman-Alpha Absorption Hygrometer. In: Moisture and Humidity 1985: Measurement and Control in Science and Industry. Washington, D.C. Ed. Instrument Society of America. ISBN 0-87664-865-0.

Other references can be found starting from there.