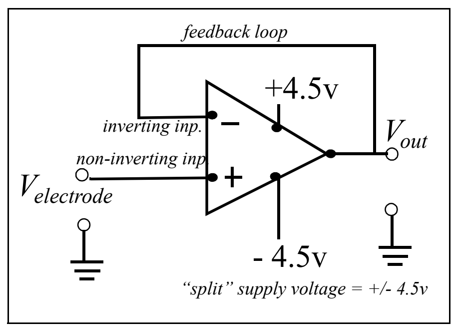
Water Resources - Experiment #1

Appendix 2: *Signal Conditioning Circuit - with op-amp*

The glass electrode is but one component of our pH sensing system. Sensor systems generally include, in addition to a *transducer* (the glass electrode), a *signal conditioning* component, a *data transmission* component and, back home, a *data readout/storage* subsystem. We are concerned here with our signal conditioning subsystem.

Because the output impedance of the glass electrode is so high, perhaps on the order of 10^{10} *ohms,* the device, considered as a voltage source, would be "loaded down" by any ordinary readout device presenting lower impedance - e.g., our digital voltmeter - and hence the voltage the latter displayed would not be a true measure of *pH*.

To ensure we do get a true reading, we use an operational amplifier ("op-amp") that presents a high impedance, much higher than that even of the electrode, to the electrode's output. In this case, the op-amp will draw very little current - in fact we assume it draws none - so the input to the op-amp will be the true voltage. The circuit is designed such that the output of the op-amp is equal to its input and delivers adequate current to our digital voltmeter, readout. How this works we now attempt to explain.



A schematic of the signal conditioning circuit is shown in the figure. To understand its function we note first that an op-amp, in open loop mode (no feedback loop) has enormous gain - on the order of 10^5 or 10^6: That is, if the voltage difference between the noninverting and inverting inputs differs from zero - say the noninverting voltage input *exceeds* the voltage at the inverting input then V_{out} will grow *positive* - big time[1]. (Actually it will grow until it reaches the supply voltage of +4.5 volts and be nailed there). Conversely, if the noninverting voltage input *drops below* the voltage at the inverting input - V_{out} will grow *negative,* big time.

Now consider what happens with the feedback loop in place - connecting the output to the inverting input - so that V_{out} is held to the voltage at the inverting input. (The resistance of the feedback line is taken as zero). If the voltage at the *non*inverting input differs from the voltage at the inverting input - say it increases relative to the latter - then V_{out} will increase due to the op-amp's gain. But it can't increase "big time" because once it, and consequently the inverting input voltage, reaches the voltage at the *non*inverting input, growth must cease for any further increase would produce a *non*inverting voltage dropping below the voltage at the inverting input and V_{out} would

1. The labeling of the two inputs to the op-amp as "inverting" and "noninverting" will be explained in time. Roughly speaking, the output of the op-amp is out of phase with an inverting input by 180^o while the noninverting input is in phase with the output. The plus and minus signs do *not* mean that a negative voltage must be supplied to the inverting input, nor a positive voltage to the non-inverting input.

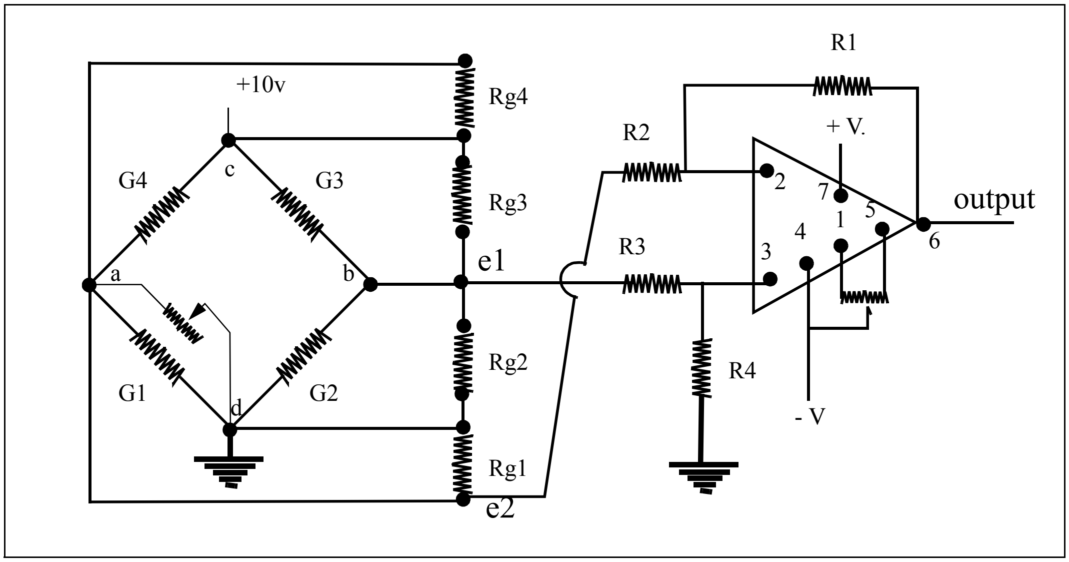
correspondingly decrease. The result is that for changing $V_{electrode}$ the output voltage “follows” the input voltage[1].

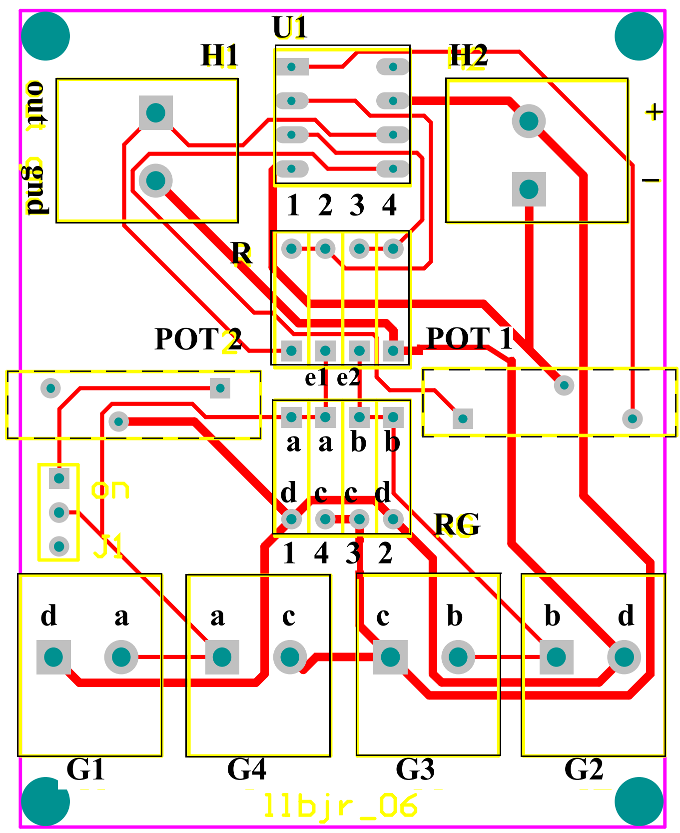
$$V_{out} = V_{electrode}$$

Since the op-amp presents such a high impedance to the glass electrode (in fact the argument above assumed infinite impedance) the $V_{electrode}$ is truly $V_{electrode}$ and we have successfully conditioned our raw signal as presented by our transducer.

1. An op-amp used in this way is called a “follower”. Ref: P. Horowitz, W. Hill, *The Art of Electronics*, Cambridge University Press, 1980, p. 176 (1999 edition).

Circuit board layout.





Top figure is circuit diagram as it would appear in a text book. The bottom figure is the printed circuit board layout. (Overwritten to make readable).

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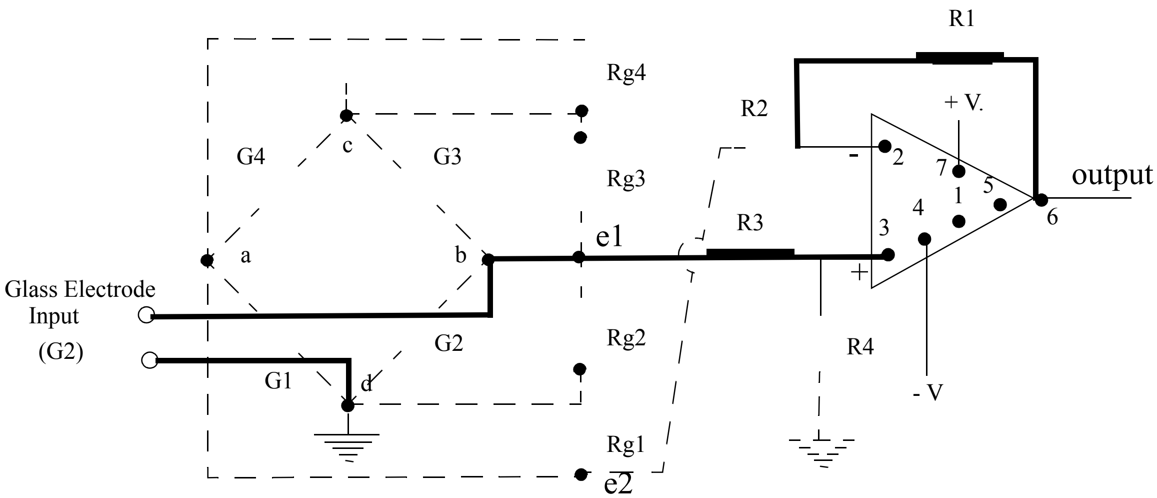

The above shows the signal conditioning circuit for use with the Glass Electrode. The full circuit, including the “bridge” will be used in the structure’s lab.