clusion; 0.01 mM NaCN reduced the rate in the dark to 60 percent of the control, but in the light it was 98 percent or more. Because cyanide inhibits the cytochrome system (*10*), it should decrease the supply of high-energy phosphate compounds more in dark than in the light due to the fact that in the light these compounds could be formed from light-dependent processes (photophosphorylation) (*4*). The absorption of potassium by corn leaf tissue in the light is closely coupled to the energy supplied by light-dependent processes, while in the dark the energy for active potassium accumulation is obtained through respiratory pathways, as in nonphotosynthetic tissue.

DONALD W. RAINS
Kearney Foundation of Soil Science, University of California, Davis 95616

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Pulmonary Ventilation Measured from Body Surface Movements

Abstract. *Changes in anteroposterior diameters of the rib cage and abdomen are sensed with magnetometers and summed to give outputs which are very nearly linearly related to changes in lung volume. The volume events of breathing can be measured without recourse to a mouthpiece or face mask, other than for calibration, and with minimal encumbrance to the subject.*

Pulmonary ventilation is commonly measured directly, either as volumes of gas displaced in and out through the airways, or as volumes displaced by the body surface. Because direct methods involve mouthpieces, face masks, or neck seals, they are cumbersome and impractical for prolonged measurement. They also tend to make the subject aware that his breathing is being measured, which in itself influences breathing, and they limit the subject's range of activity. For these reasons indirect methods have been sought. These have included devices which sense movements or changes in electrical properties of the chest wall, or some combination of these (*1–3*). A difficulty has been that the chest wall not only changes volume with breathing, it also changes shape. The shape depends on such matters as the nature of the act of breathing—for example, whether or not the subject is talking—on restrictions offered by clothing, and on posture and activity. To compensate for changes in shape, measurements have been made at more than one site.

Recently Konno and Mead showed that, to a useful approximation, the changes in shape can be accounted for by treating the chest wall as a system with only two degrees of freedom, the volume change of the rib cage accounting for one and that of the abdomen for the other. They further demonstrated that the volume change of each was very nearly linearly related to changes in anteroposterior diameters (*4*). Here we describe an improved transducer system for recording these diameters, as well as a convenient way to mix the signals in order to give an output proportional to total change in lung volume.

Our approach has been to measure at one body surface the strength of a magnetic field generated at the opposite surface. Identical coils are used, both to generate and to sense the fields. Two pairs of coils are oriented with their long axes in the horizontal (transverse) plane and at right angles to the sagittal plane, at the midline at the level of the nipple and umbilicus, respectively. Since the axes of the coils remain parallel, and the magnetic field produced is dipolar, the voltage induced in the receiving coil is inversely proportional to the cube of the coil separation. Because the changes in diameter are small relative to the absolute diameters, the relationship between voltage change and diameter change may be reasonably approximated as linear during ordinary breathing.

Figure 1 gives the wiring diagram for the apparatus along with the coil specifications. The coils are held within rubber sleeves, glued to aluminum plates. The aluminum plates are fixed to the skin by means of flexible plastic discs with adhesive coatings on both surfaces. The coils are further supported either with strips of adhesive tape or by means of rubber straps such as are used to hold electrocardiographic electrodes in place. The pairs of coils are tuned and driven at their resonant frequencies of 600 and 1390 cycle/sec, respectively. At these frequencies the influence of tissue (or gas) on the magnetic field strength is negligible. Cross talk is reduced to acceptable levels with filters.

In use, the outputs of the two channels are summed and their relative gains adjusted so that when, at constant lung volume (nose clip in place and mouth closed), the subject voluntarily shifts volumes back and forth between rib cage and abdomen, the summed output remains constant. (This maneuver is most easily accomplished by alternately relaxing and contracting the muscles of the abdominal wall.) At constant lung volume, any volume change of the rib cage must be equal and opposite to that of the abdomen. Therefore, if the relative gains are adjusted so that the summed output remains constant during the iso-volume maneuver, each signal must bear the same relationship to volume change, and their sum must have a fixed relationship to the total volume change of

Table 1. Simultaneous measurements of minute ventilation (liter/min ATPS), estimated spirometrically (s) and from chest wall measurements (w) (see *5*).

Rest		Rebreathing		Exercise	
s	w	s	w	s	w
		Subject E.B.			
4.7	4.2	24.5	23.2		
		64.2	63.3		
		Subject J.B.			
10.4	9.8	17.8	17.2		
		52.8	54.0		
		Subject D.L.			
7.2	6.3	19.6	16.4		
		67.2	61.6		
		Subject J.M.			
6.6	6.4	13.8	12.8	18.8	17.5
		26.0	25.0	38.4	35.7
		Subject T.T.			
9.6	9.5	35.3	36.0	26.2	27.0
		55.0	59.5	40.1	45.5

the respiratory system during actual breathing. This relationship is defined by relating the summed output to known volume changes measured spirometrically, either at the mouth or with a body plethysmograph.

Figure 2 presents simultaneous tracings during voluntary maneuvers in which the subject intentionally changed the shape of his chest wall as he breathed (channel 1 presents the rib cage motion, and channel 2, that of the abdomen). Despite the wide variation in the relative contributions of the rib cage and abdomen, including maneuvers in which the movement of the two regions were paradoxical, the summed signal (channel 3) continued to reflect lung changes closely (channel 4).

Table 1 summarizes simultaneous measurements of minute ventilation estimated from chest wall measurements and spirometrically (*5*) in subjects at rest and exercising, as well as during hyperventilation induced by rebreathing from a 7-liter spirometer. All measurements were made with the subject in the upright posture. The tidal volume in these measurements did not exceed 50 percent of the individual's vital capacity.

We have not compared measurements in different postures or on different occasions. The stability on a given occasion over periods up to 1 hour appears to be excellent to the extent that a single adjustment of relative gains and a single volume calibration suffice. The simplicity, relative insensitivity to change in shape of the chest wall, and lack of encumbrance to the subject recommend the method for measurements of minute ventilation in instances where direct measurements are inconvenient or impossible.

JERE MEAD
NORMAN PETERSON
GUNNAR GRIMBY
JUDSON MEAD

Department of Physiology, Harvard School of Public Health, Boston, Massachusetts, and
Department of Geology, Indiana University, Bloomington

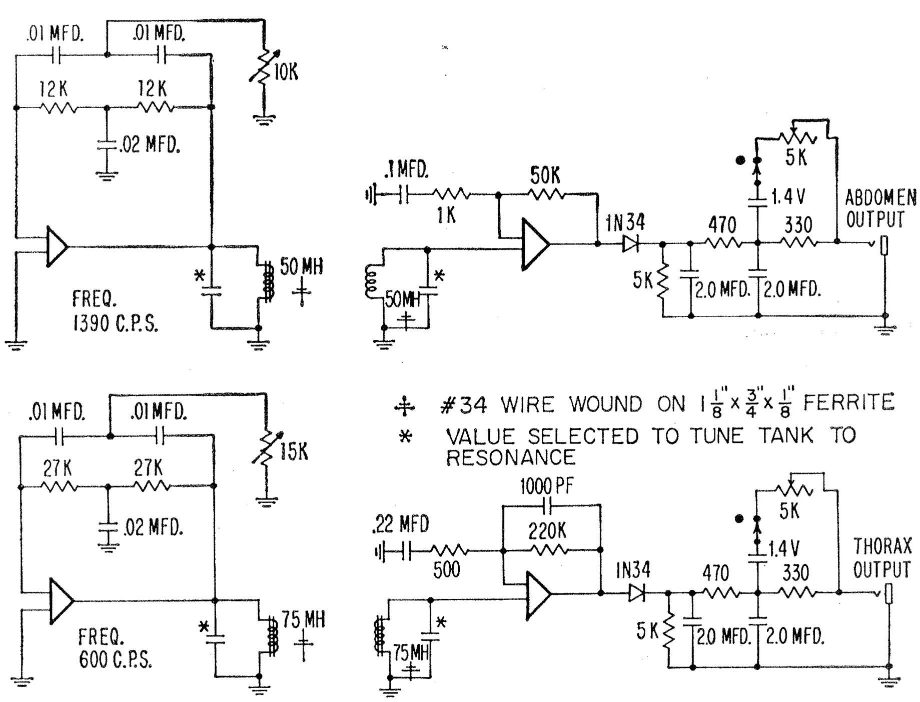

Fig. 1. Wiring diagram and coil specifications for the transducers.

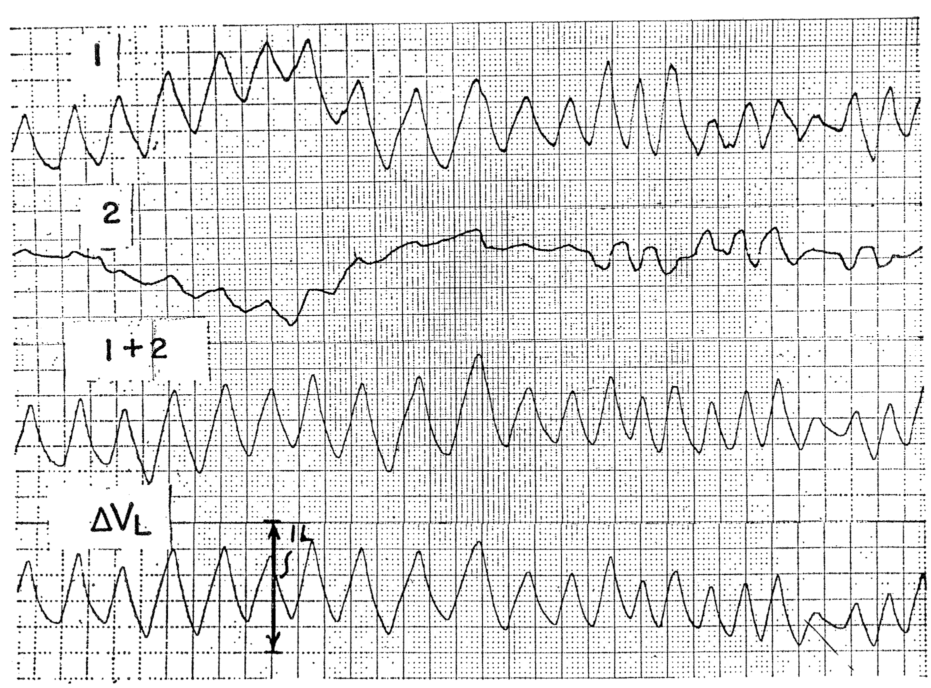

Fig. 2. Simultaneous tracings of changes in anteroposterior diameters of the rib cage (channel 1), abdomen (channel 2), and the sum of 1 + 2 (channel 3), along with the simultaneous tracings of changes in lung volume (ΔV_L) measured spirometrically (channel 4). The time scale is 2 seconds per division, or approximately 1 minute from margin to margin.

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