MOUNTAIN MEASUREMENTS.

I.—THE GENERAL PRINCIPLES.

By J. C. Barnett.

What mountaineer is there who has not felt his pulses thrill when, in some wild and silent solitude, he gazed upon the station cairns and altitude marks that reveal the passage of the ubiquitous Survey Sappers? Is there a mountaineer who does not cherish those marvellous maps which were the outcome of that arduous and stupendous undertaking that for so many years occupied the attention of those true mountaineers, sending them to knolls and ridges, to downs and uplands, to moors and fens, to Highland glens and mountain peaks, to river brink and ocean beach, to make those skilful observations, accurate measurements, and careful calculations that have resulted in placing in our hands those magnificent contour maps which have guided our footsteps and gladdened our hearts many a time and oft? A few facts concerning the general principles of mountain measurements, the instruments used, and the difficulties encountered in striving after accuracy, should, therefore, prove interesting to hillmen and others.

If any one prefers the cold of winter to the warmth of summer, it is not necessary that he should wait the revolving seasons to bring about the realisation of his desires; he has simply to make a long journey to the north, or take a short flight upwards, for above our heads at all seasons of the year is a region of eternal chill. A climb of 16,400 feet in Tropical Africa brings one into a region of perpetual snow; in Switzerland the snow line is reached at 9000 feet above sea level; in the south of Norway at 4500 feet; in the north of Norway at 1000 feet; while a little nearer the pole the snow line is at sea level. Ben Nevis comes short of a perpetual crown of snow by 150 feet. A journey northwards of about 60 miles, or a flight upwards of 300 feet, is marked by a fall in temperature of 1° F. It is easily seen why a journey to the north should bring us to regions of greater cold, because the higher the latitude the lower will the sun appear to rise in the southern sky, and the greater the angle will be at which his rays strike the earth. The consequence of this is that fewer rays will fall upon a given space, and less will be the resulting heat. Besides, the greater the angle of incidence of the sun's rays, the greater the thickness of atmospheric air to be traversed, and the greater the loss of heat by reflection, refraction, and absorption. At the poles the sun never rises higher than $23\frac{1}{2}°$ above the horizon, and, consequently, the amount of heat received from the sun is comparatively small. Why the air becomes colder, however, as we ascend, and so get nearer the source of heat, is not so easily understood, and as this varying temperature has much to do with the determination of mountain heights by means of the barometer, a word or two regarding how the air is warmed may not be out of place.

Dry air is diathermanous, that is, it permits the heat rays to pass through it without warming it; but water vapour, which exists in ever-varying quantities in the lower regions of the atmosphere, absorbs and retains a fair proportion of the heat that speeds onward from sun to earth. When the heat waves beat upon the earth its temperature is raised, and the luminous heat rays, being changed into dark ones, are radiated into space. The water vapour steps in once more, and, acting as a blanket, intercepts the radiant heat, and prevents the cooling of the earth and lower layers of the atmosphere. A sheet of vapour thus acts as a screen to the earth, as it exercises a strong absorbent action on the radiation from the sun, and a still stronger action of a similar kind on the radiation from the earth. If the air were dry, the radiation would proceed unchecked, and the temperature of the earth soon after sunset would fall far below the freezing point. At Davos, in Switzerland, at a height of 5000 feet, one can, even in mid-winter, sit comfortably in the sun without an overcoat, while in the shade close by the thermometer shows several degrees below the freezing point. Contrasts of this kind occur wherever the air is unusually dry. The cold on mountain tops may be partly accounted for in this way, and partly by the fact that, as the columns of heated air rise from the earth into the higher regions, where the pressure of the superincumbent air is less, this heated air expands, and, as its heat is converted into the work of expansion, a chilling effect is the result. The rarity of the atmosphere on mountain summits, then, is produced by the conversion of heat into work.

All mountaineers by experience are acquainted with the fact that the temperatures on mountain tops are lower than those on the plains below as a general rule, and that this difference is greater during the day than during the night, and in summer than in winter. The reasons for this will be at once understood if we bear in mind that the higher the elevation:—

1. The drier the air, and consequently the greater the radiation.
2. The less the pressure, the more expanded the air, and the greater the quantity of heat used up in work.
3. The less the land surface to be heated by the sun's rays, and the less the surface to heat the air.

In cases of severe frost, however, it is generally found that the temperature increases with the height, giving the well-known phenomenon of the "up-bank thaw", when the snow thaws on the uplands while the lowlands are in the grasp of a severe frost. When Piazzi Smythe ascended to the top of the peak of Teneriffe a fearful thunderstorm burst on the island, and much sympathy was felt for the poor scientist exposed to the full fury of it on the bare peak; but the great astronomer was above the clouds and bathed in the warm rays of a noonday sun, while the storm raged furiously at his feet. The sympathy was wasted. In the same way we often waste sympathy upon the winter mountaineer, forgetting that the intense cold at the mountain base may give place to a much more genial condition of things two or three thousand feet higher up.

If the air were perfectly dry, then, the thermometer would fall 1° F. for every 180 feet of ascent, but as the atmosphere contains moisture in the form of aqueous vapour, which gradually condenses into cloud, rain, &c., much latent heat is given out, the temperature is raised, and the rate of cooling for ascent diminished. We have in consequence to ascend 300 feet to produce a fall of 1° F.

From what has been said it will be seen that the thermometer by itself would make a very uncertain instrument for determining mountain heights, for in calm weather the cold air sinks to the valleys, and a house on a hill preserves an immunity from frost. But though the indications of the thermometer are thus of but little value in themselves in enabling us to calculate elevations, yet in conjunction with the barometer it is invaluable.

Not only does the temperature of the air fall as we ascend, but its pressure or weight diminishes also. The variation of pressure is determined by the barometer, and varies with temperature, moisture, and elevation :—

Temperature.—The greater the heat the more will the air be expanded, the lighter, bulk for bulk, will it become, and the further will the barometric column fall.

Moisture.—As water vapour is lighter than dry air in the ratio of 29 to 18, any mixture of the two must be lighter than dry air, and so the presence of water vapour will be indicated by a low barometer.

Elevation.—It has been ascertained by observations on meteorites that the air ocean, which surrounds us on all sides, extends upwards to a height of 200 miles. As the barometer is affected only by the air above it, it is clear that the higher we ascend the lower will the barometer sink. Glaisher, in his famous balloon ascent, recorded that the barometer stood at 9·75 inches at the height of 29,000 feet, when he lost consciousness ; and Coxwell observed that the barometer indicated 7 inches before the descent began. This was at a height of 37,000 feet, showing that three-fourths of the total mass of air lay beneath them.

The barometer may, in consequence of this varying pressure at different elevations, be used to measure heights above or depressions below sea-level, and in a general way in this country we estimate that the fall of an inch indicates an ascent of 900 feet. When, however, one begins to measure mountains by the barometer with a desire to obtain accurate results, many things have to be taken into account and allowed for. Some of these "corrections" have reference to the individual instrument used, and some are applicable to all barometric readings. Of the latter the principal corrections are for temperature, altitude, and gravity:—

Temperature.—As heat expands the mercurial column the height of the mercury will not be all due to the pressure of the air, and so for purposes of comparison all barometric readings are reduced to what they would be were the temperature of the air 32° F.

Altitude.—In order that barometric readings at different places may be compared, it has been agreed to reduce all to their equivalents at the same sea-level. For this purpose the mean sea-level at Liverpool is taken in this country.

Gravity.—As the earth is not a perfect sphere, but is flattened at the poles and bulged out at the equator, and as the weights of bodies depend upon their distances from the earth's centre, it follows that bodies at the equator weigh less than they would do if transferred to either pole. The weight of mercury, as well as every other substance, will thus vary with the latitude, and so it has been found advisable to reduce all barometric readings to what they would be at latitude 45°, and thus eliminate the effect of gravitation.

The temperature at which liquids boil depends upon atmospheric pressure, the boiling point of a liquid being that temperature at which the pressure of the vapour inside the liquid is equal to the atmospheric pressure outside. The boiling point will be lowered as we ascend a mountain, and raised as we descend a mine. A very portable and convenient instrument, called the hypsometer, has been constructed for determining heights by the temperature of boiling water, and it has proved very useful as a check on the results obtained by the mountain barometer.