On the other hand, the following relation is easily established: For a balloon having only itself to carry and in equilibrium at a pressure of $1/n$,

$$V = \frac{36\,\pi m^3 n^3}{A^3}.$$

V = volume of the balloon in cubic meters.

m = superficial density of the envelope (weight in kilograms per square meter).

n, the reciprocal of the pressure as defined above.

A, ascensional force, in kilograms, of a cubic meter of gas at a pressure of 1 kilogram per square centimeter.

This equation between three cubics shows with what rapidity the volume of the balloon increases as the envelope becomes heavier, as the final pressure diminishes, and as the density of the gas approaches that of the air.

Illuminating gas has an ascensional force equal to two-thirds of that of ordinary hydrogen. The substitution of that gas for hydrogen would have the effect of increasing the volume of the balloon in the proportion of 2^3 to 3^3 or of 1 to 3.38. It is, therefore, necessary to use hydrogen.

The ordinary material of manned balloons weighs 300 grams per square meter. I have succeeded in making one that weighs 50 grams per square meter. This substitution reduces the volume of the balloon in proportion of 216 to unity.

Let us, therefore, use this lighter covering (or $m = 0.050$) and ordinary hydrogen, for which $A = 1.122$. The cubical equation now becomes—

$$V = 0.01\ n^3.$$

This gives an astonishing progression, as follows:

n	5	10	40	300	500
y in meters	12900	18400	29500	42300	49700
V in cubic meters	1.25	10	640	80000	1250000

The figures in this table speak for themselves.

The atmosphere, at first so easy to ascend, seems soon to be bounded as by a brass ceiling. Heights of 12 to 15 kilometers can be attained with small spheres of a few cubic meters; twice that altitude requires hundreds; thrice, requires tens of thousands; four times that height, millions of cubic meters.

By eliminating n from the above equation in three cubics, we find that the expression for the altitude may take the form—

$$y = M + 6133 \log V,$$

where M is a constant that is a function of m and A only.

If we put $y = h - h_1$ = altitude above the plane for which the pressure is unity and $n = \frac{1}{p}$ = reciprocal of the pressure at the altitude F, we obtain the formula as written by M. Renard.

$$y = 18400 \log n.$$

The relation between n and p may also be expressed in the following table:

b. Barometrical column.	p. Pressure in kilograms per square centimeter.	$n = 1/p$.
Millimeters.		
800	10.877	0.09194
760	10.333	0.09678
720	9.789	0.10216
680	9.245	0.10817
640	8.701	0.1149
600	8.158	0.1226
560	7.614	0.1313
520	7.070	0.1414
480	6.526	0.1532
440	5.983	0.1671
400	5.439	0.1839
300	4.079	0.2452
200	2.720	0.3676
100	1.360	0.7353
73.55	1.000	1.00
36.8	0.500	2.00
24.5	0.333	3.00
18.4	0.250	4.00
14.7	0.200	5.00
7.4	0.100	10.00
9.8	0.025	40.
0.22	0.003	300.
0.15	0.002	500.

If we make $A = 1.122$, as for common hydrogen, the value of M becomes—

$$M = 11675 - 18400 \log m.$$

The first equation shows that by increasing the volume tenfold, y is increased by a constant quantity equal to 6133 meters only.

These two equations enable me to construct some diagrams illustrating, so to speak, the obstacle that opposes the ascensions of our sounding balloons.

The level lines of these diagrams correspond to constant values of V; by giving to V values differing successively by 1 square meter the level lines are seen to draw closer together and coalesce in one continuous line. This is a first limit, which can only be passed over by increasing tenfold the order of the size of the volumes.

At 6133 meters higher there is a new limit rendering a new tenfold increase, and so on.

The other diagrams show the influence of the weight of the covering m and of the probable load of the balloon.

I now come to the construction of the sounding balloon, which I expect soon to try. I have been able to limit its diameter to 6 meters and its volume to 113 cubic meters, by making use of a very light covering of Japanese paper rendered waterproof by a special kind of varnish. This covering weighs only 50 grams per square meter.

In regard to the instruments, I first turned my attention to the barograph and the thermograph.[2] M. Richard furnished me with instruments weighing 2.8 kilograms each; by the use of aluminium and by cutting out whatever was unnecessary I have reduced their weight to 1200 grams each.

My great anxiety was to preserve the apparatus from shocks on landing; the parachute which I present to the academy resolves this problem appropriately. It consists of a cage which may be thrown from a height of 2 meters upon a hard soil without at all interrupting the movements of the clockwork of the instruments placed within it.

All this apparatus is nearly completed. First, there is the net of linen thread, weighing only 0.632 kilograms, and breaking only by a strain of 650 kilograms. I have the honor, also, to present the barograph, the thermograph, their protecting cages and parachutes, and, finally, several samples of the covering of the balloon. The total weight, including instruments, will not exceed 9.5 kilograms.

The altitude reached will be about 20,700 meters and the pressure at the moment of stopping will be reduced to 55 millimeters of mercury.

My object in making this communication is not by any means to lay claim to priority in the conception of these aerial soundings; I have simply wished to define the limits imposed upon us by the nature itself of the matter and, in the second place, to make known the results of my investigations into the subject of the light coverings, instruments, and light parachutes, without which a continuous and regular series of aerial soundings is practically impossible.

ON THE ASCENSION OF CLOSED RUBBER BALLOONS.

By H. HERGESELL. (Translated from the Illustrirte Aëronautische Mittheilungen, May, 1903, Vol. VII, pp. 163–168.)

A balloon whose envelope consists of very extensible india rubber, can be used for ascensions when it is tightly closed. The great advantage of this is that in ascending no loss of gas takes place; in going up, the balloon will expand more and more and can attain great heights before bursting. The ascent ceases when a rent occurs in the envelope. If instruments are carried up, an arrangement must be provided that will prevent a precipitous descent. Assmann, to whom we are indebted for the method just described, of employing

[2] M. Violle is just now having a light actinometer constructed for these experiments. M. Ch.-Ed. Guillaume is occupied with a bathometer.

closed balloons, utilizes a parachute for this latter purpose. On the other hand, a somewhat smaller and less inflated second balloon may be used in the same way; this would burst later on account of being less distended, and would begin to fall to the ground immediately after the bursting of the larger balloon. This smaller balloon offers enough resistance to the air to prevent a rapid fall, and as it is sufficiently filled to float alone, may serve as a signal balloon to attract the attention of those in quest of the instruments.

In the following paragraphs the conditions of ascension of a distended balloon will be more closely examined:

Let the mass of the gas in the balloon be M kilograms and the volume at any time V, then we have the relation $M = Vs_g$, where s_g expresses the specific weight of the interior gas.

If B is the weight of all solid parts of the balloon (the envelope, the parachute, the instruments, etc.) then the force of ascension or buoyancy is:

$$A = V(s_a - s_g) - B = M\left(\frac{s_a}{s_g} - 1\right) - B,$$

where s_a is the specific weight of the air. Let n be the ratio of the specific weight of the air and of the buoyant gas, then $A = M(n-1) - B$, so that when M and B are constant, A will depend only on n. The laws of gases give us the relation

$$s_a = s_{ao}\frac{p_a}{p_o}\frac{T_o}{T_a}$$

$$s_g = s_{go}\frac{p_g}{p_o}\frac{T_o}{T_g},$$

where s_{ao} and s_{go} are the specific weights for a given pressure p_o and for a certain temperature T_o (in absolute measurement).

It therefore follows that

$$n = \frac{s_{ao}}{s_{go}} \times \frac{p_a}{p_g} \times \frac{T_g}{T_a} = n_o\frac{p_a T_g}{p_g T_a}.$$

In consequence of the pressure of the elastic balloon envelope, p_g will in general be somewhat larger than p_a. For the same reason T_g will differ from T_a by a certain amount. If we put $p_g = p_a + \varDelta p$ and $T_g = T_a + \varDelta T$, then

$$n = n_o\frac{p}{p + \varDelta p}\cdot\frac{T + \varDelta T}{T}.$$

The magnitude of $\varDelta p$ can be learned by experiment. For this purpose an india rubber balloon was gradually filled, and the excess of pressure was measured by an attached water manometer. At each step the volume was determined simultaneously. The following table contains some of the results:

TABLE 1.

Diameter.	Volume.	Excess of inside pressure of mercury.
Millimeters.	*Cubic centimeters.*	*Millimeters.*
0.81	0.38	20.0
1.08	0.59	27.5
1.42	0.89	26.8
1.72	1.18	24.5
1.82	1.29	22.5
2.40	1.95	21.1
2.66	2.27	20.0
3.02	2.83	19.5
3.72	3.76	17.3
4.28	4.64	15.7
4.62	5.20	17.5
5.02	5.87	16.3
5.20	5.92	16.5

We see, therefore, that the pressure increases at first with increasing volume. A certain maximum is, however, soon attained, and this occurs with a relatively small increase in the volume of gas. As the balloon expands still further the pressure again decreases. The bursting of the balloon occurs at a comparatively small pressure. This phenomenon is undoubtedly connected with the elastic behavior of the caoutchouc. In every case the experiments show that $\varDelta p$ at bursting was less than 2 millimeters of mercury. We may neglect the excess of pressure without serious error.

It is difficult to determine by experiment the magnitude of $\varDelta T$, as it depends upon the influence of radiation on the balloon. According to measurements already mentioned in this periodical (Illustrirte Aëronautische Mittheilingen, III, 1899, p. 109), the amount of excess may become very considerable. It is, however, to be observed that india rubber balloons must always be inflated with compressed hydrogen, so that the gas is comparatively cool when it enters into the balloon. On this account the equality of the inner and outer temperature will first occur at some definite altitude and $\varDelta T$ will become positive from this point upward. If we put $\frac{\varDelta T}{T} = \tau$, then $n = n_o(1+\tau)$ and $A = M[n_o(1+\tau) - 1] - B$.

We will now compute the volume and thence the radius of the inflated balloon, which corresponds to a definite air density, s_a.

From the equation $M = Vs_g = \frac{Vs_a}{n}$ there follows

$$V = \frac{Mn}{s_a}.$$

If we take n as a constant, that is to say, if we ignore the influence of the temperature of the interior gas, then v is inversely proportional to the density of the air.

Since $V = 4\pi r^3/3$ it follows that the diameter of the balloon is given by the equation

$$d = \sqrt[3]{\frac{6Mn}{\pi}} \times \frac{1}{\sqrt[3]{s_a}}.$$

If d_o is the diameter when the density is s_{ao}, then we have

$$\frac{d}{d_o} = \sqrt[3]{\frac{s_{ao}}{s_a}}.$$

If we do not ignore the influence of temperature, then the last formula will be

$$\frac{d}{d_o} = \sqrt[3]{\frac{s_{ao}}{s_a}\cdot\frac{n}{n_o}} = \sqrt[3]{\frac{s_{ao}}{s_a}(1+\tau)}.$$

Hence, the diameter of an inflated balloon at different altitudes varies inversely as the cube root of the density of the air at those altitudes. It is more convenient to introduce the air pressure instead of the air density. The formula then becomes

$$\frac{d}{d_o} = \sqrt[3]{\frac{p}{p_o}\frac{T_o}{T}(1+\tau)}$$

which may be written approximately thus:

$$\frac{d}{d_o} = \sqrt[3]{\frac{p}{p_o}}$$

The rate of ascension of a self-registering balloon is of the greatest interest, since this regulates the ventilation of the thermometer carried up with it. During the ascensional movement the resistance of the air at any moment is very nearly equal to the buoyancy. If we call the cross section of the ascending system Q, the vertical velocity v, and the coefficient of resistance k, therefore we have

$$kQv^2 s_a = A = M(n-1) - B.$$

From this there follows

$$v^2 = \frac{A}{kQs_a}.$$

We must express Q as a function of s_a; we have

$$d = d_o\sqrt[3]{\frac{s_{ao}}{s_a}},$$

and consequently,

$$A = \frac{d^2\pi}{4} = \frac{\pi d_o^2}{4}\left(\frac{s_{ao}}{s_a}\right)^{\frac{2}{3}},$$

so that for v^2 we have:

$$v^2 = \frac{4A}{\pi k d_o^2 s_{ao}^{\frac{2}{3}}} \sqrt[3]{\frac{1}{s_a}},$$

for which we can also write,

$$v^2 = \frac{4A}{\pi k d_o^2 s_{ao}} \sqrt[3]{\frac{s_{ao}}{s_a}}.$$

But $v^2_0 = \frac{4A}{\pi k d^2_o s_{ao}}$ is the vertical velocity of ascent, corresponding to a definite density s_{ao} of the air, and to the corresponding buoyancy appropriate to it. With this notation we obtain

$$v^2 = v_0^2 \sqrt[3]{\frac{s_{ao}}{s_a}} \quad \text{or} \quad v = v_0 \sqrt[6]{\frac{s_{ao}}{s_a}},$$

or approximately

$$v = v_o \sqrt[6]{\frac{p_o}{p}}.$$

Hence, the velocities of ascent are inversely as the 6th root of the corresponding air pressures.

According to the preceding the maximum height that an elastic balloon can attain depends not at all on the size of the balloon, the nature of the gas with which it is filled, etc., but only upon the capacity of the material for elastic expansion. The greater the volume of the elastic covering can become without bursting, so much the greater the height. The size of the balloon is only to be considered in so far as that it must be sufficient, without being too greatly expanded, to give the buoyancy necessary in order to raise the balloon and the instruments. The balloons used heretofore, as furnished by the Continental Gummifabrik in Hanover, can easily stretch to double their diameter without bursting. Therefore, the height they will attain is about 18,000 meters.

The following table will be of use in the employment of india rubber balloons. The first column shows the density of the air, the second the altitude, the third the ratio $\frac{d}{d_o}$, the fourth the ratio $\frac{v}{v_0}$, the fifth the ratio of the ventilation, or of the mass of air flowing past the balloon.

TABLE 2.

Density of the air.	Altitude.	d/d_o	v/v_o	q/q_o	Density of the air.	Altitude.	d/d_o	v/v_o	q/q_o
	Meters.					*Meters.*			
1.25	20	1.00	1.00	1.00	0.50	8500	1.36	1.16	0.46
1.19	500	1.02	1.01	0.96	0.47	9000	1.39	1.18	0.44
1.13	1000	1.04	1.02	0.92	0.45	9500	1.41	1.19	0.43
1.07	1500	1.05	1.03	0.88	0.42	10000	1.44	1.20	0.41
1.01	2000	1.07	1.04	0.84	0.37	11000	1.49	1.22	0.36
0.96	2500	1.09	1.04	0.80	0.32	12000	1.57	1.25	0.32
0.91	3000	1.11	1.05	0.77	0.27	13000	1.67	1.29	0.28
0.87	3500	1.13	1.06	0.74	0.23	14000	1.76	1.33	0.25
0.82	4000	1.15	1.07	0.70	0.19	15000	1.87	1.36	0.21
0.78	4500	1.17	1.08	0.67	0.18	16000	1.91	1.38	0.20
0.74	5000	1.19	1.09	0.65	0.16	17000	1.99	1.41	0.18
0.70	5500	1.21	1.10	0.62	0.14	18000	2.07	1.44	0.16
0.66	6000	1.24	1.11	0.58	0.12	19000	2.18	1.48	0.14
0.63	6500	1.26	1.12	0.56	0.11	20000	2.25	1.50	0.13
0.59	7000	1.29	1.13	0.54	0.08	22000	2.27	1.51	0.10
0.56	7500	1.31	1.14	0.51	0.06	24000	2.28	1.51	0.08
0.53	8000	1.33	1.15	0.49					

Table 2 shows that very considerable heights can be attained with closed rubber balloons if they can expand to more than twice their original diameter. In practise, however, the misfortune is often noticed that the envelopes in expanding develope small holes through which the gas rapidly escapes. In such cases it happens that the balloons do not explode although the altitudes that they can attain under such circumstances are very considerable, such as 12,000–13,000 meters.

However, in such cases we lose one advantage which Assmann more especially has pointed out, namely, that a closed balloon ascends with increasing velocity and does not maintain any position of equilibrium. The leaky balloon floats for some time at the highest altitude, so that the thermometers have no proper ventilation, and then descends too slowly. On this account, it would be well in all cases to give the balloon, by a strong distension in the beginning, a more than sufficient upward impulse, so that in the first place it will certainly explode, and in the second place be sufficiently ventilated. The fact that the velocity varies inversely as the 6th root of the pressure, therefore, increases somewhat slowly, makes a great velocity in the beginning particularly desirable.

If we take the product of the vertical velocity by the density of the air as the measure of the ventilation, then in the vicinity of the surface of the earth and at 4 meters per second this will be 5, but at an altitude of 20,000 meters where the velocity, according to our table, has risen to 6 meters per second, the ventilation will be 0.65. The latter figure is certainly no longer sufficient to protect even well sheltered thermometers against radiation. According to our experience we must attain a value of 1. This figure, however, requires an initial ascensional velocity of 5.7 meters per second, a velocity that can easily be given to rubber balloons. For still greater maximum altitudes a still greater initial velocity must be given. For these ascending velocities, however, one must use very sensitive instruments and not sluggish thermometers. In Strasburg, since the introduction of the closed rubber balloons, we have with great success used the tubular thermometer, described by me in the protocol of the Conference of the International Commission for scientific balloon ascensions at Berlin. This thermometer has a sensitiveness more than sufficient to enable it to record properly during the above desired velocity of ascension; it also possesses the lightness (weighing with the clock and protecting case 560 grams) necessary to make it possible to rise with rubber balloons of 1.50 meters diameter.

The further advantages possessed by the rubber balloons have been so fully described by the inventor, Dr. Assmann, in the protocol to the above-mentioned conference that I do not need to go into any further details. I will only close with the wish that they may be used frequently and with good results.

DETAILED CLOUD OBSERVATIONS. A PROGRESSIVE PHASE IN WEATHER FORECASTING.

By Rev. FREDERICK L. ODENBACH, S. J., dated January 8, 1904, Meteorological Observatory of St. Ignatius College, Cleveland, Ohio.

Isobars have formed the stepping stones on which weather forecasting has mounted to take its place among the sciences. The daily survey of the atmosphere and the publication of weather maps have enabled meteorologists to bring out these facts; that the *nature* of our weather depends on the configuration of isobaric lines, but its *intensity* on their gradient. With these two principles to start with, a few decades have sufficed to develop a method of forecasting that has met with very encouraging results and has been of great value to most varied classes of interests. But, in spite of these successes, there is a prevailing conviction among forecasters that in the face of great difficulties progress, at the present time, is checked.

In spite of telegraphic systems and the map material at our disposal twice each day, certain obstacles bar our further advance which may be summed up as follows:

1. We miss many an important detail in the map.

2. We are often left ignorant of the sudden formation or dissolution of highs and lows, or of changes in their intensity.

3. The irregular progress of some isobaric systems can not be detected on, or inferred from, even the most perfect map. The initiated will hardly call for a proof of this statement. But how are we to mend our condition? A thousand stations would hardly bring out the necessary detail in a map; and, even if they did, the changes in atmospheric conditions would