the pipe into a position parallel to the initial direction, Fig. 7, we have $i = 180$ degrees, and the loss of head would be p, one-half only of that which would take place if the pipe had taken that direction by two abrupt and successive right-angled changes, Fig. 8. If there were n continuous changes of direction the loss of head would be

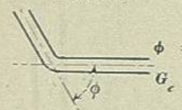
$$P_1 - p_1 = \frac{i}{180} p$$

—*Power*, February, 1900.

Weisbach, from experiments with 1¼-inch pipe (water) found the loss of head to be $h_e = G_e \frac{v^2}{2g}$,

$$G_e = 0.9457 \, sin^2 \frac{\phi}{2} + 2.047 \, sin^4 \frac{\phi}{2}$$

Elbows.—



ϕ =	20°	40°	60°	80°	90°	100°	110°	120°	130°	140°
G_e =	0.046	0.139	0.364	0.74	0.984	1.26	1.556	1.861	2.158	2.434

hence at a 90-degree elbow the whole head due to the velocity is very nearly lost.

Bends.—For curved bends, ○ cross-section, $h_b = G_b \frac{v^2}{2g}$,

$$G_b = 0.131 + 1.847 \left(\frac{d}{2r}\right)^2$$

where d = diameter of pipe, r = radius of curvature of bend.

For □ cross-sections

$$G_b = 0.124 + 3.104 \left(\frac{s}{2r}\right)^{\frac{7}{2}}$$

where s is the length of side of section parallel to the radius of curvature, r.

$\frac{d}{2r}$ =	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	○ section.
G_b =	0.131	.138	.158	.206	.294	.440	.661	.977	1.408	1.978	

$\frac{s}{2r}$ =	0.1	0.2	0.3	0.4	0.5	0.6	.07	0.8	0.9	1.0	□ section.
G_b =		0.124	.135	.180	.250	.398	.643	1.015	1.546	3.228	

CHAPTER IX

HOUSE CHIMNEYS

HOUSE-HEATING

SCHUMAN * gives these formulæ for house-heating calculations.

Let A = sectional area of flue in square feet.
V = volume of smoke delivered in cubic feet per second; usually 600 is allowed for V.
K = pounds of coal consumed per hour.
H = height of chimney in feet.
v = velocity of smoke in feet per second.
t = external temperature, average 50°.
t_1 = internal temperature, average 550°.

(58) $v = 0.08\sqrt{(t_1 - t)H}$,

(59) $A = \frac{12.5\,V}{\sqrt{(t_1 - t)H}}$,

(60) $V = Av = A\,0.08\sqrt{(t_1 - t)H}$,

(61) $H = \frac{156}{t_1 - t}\left(\frac{V}{A}\right)^2$,

allowing 600 for V, we have

(62) $A = 0.128\frac{K}{\sqrt{H}}$,

(63) $H = 0.01638\left(\frac{K}{A}\right)^2$.

The following table is adapted from the Blackmore Heating and Ventilation Company for hot-air furnaces.

* Manual of Heating and Ventilation, p. 69.

TABLE No. 28.

SIZE OF CHIMNEY FLUE.

Diameter of grate. Inches.	Area of grate. Square inches.	FLUE. INCHES. Round.	Rectangular.
16	201	9	8 × 8
18	254	9	8 × 8
20	314	11	8 × 12
22	380	11	8 × 12
24	452	14	12 × 12
26	530	14	12 × 12
28	615	16	12 × 16
30	706	16	12 × 16
32	804	16	12 × 16

H. J. Barron, New York City, gives the following:

Chimney for a small dwelling................ 8 × 8 inch, rectangular flue.
Chimney for a large dwelling................ 8 × 12 inch, rectangular flue.
Chimney for a five-story flat, 25 × 80 feet .... 12 × 12 inch, rectangular flue.
Chimney for a six-story flat, 36 × 80 feet...... 16 × 16 inch, rectangular flue.
Chimney for a church, 400,000 cubic feet..... 20 × 20 inch, rectangular flue.
Chimney for a school, 100 × 100 feet......... 20 × 20 inch, rectangular flue.
Chimney for an office building, 100 × 100 feet. 30 × 30 inch, rectangular flue.

The Herendeen Manufacturing Company, Geneva, N. Y., give:

For grates 16 inch diameter to 22 inch diameter........ a flue 8 × 8 inches.
For grates 24 inch diameter to 26 × 34 inch rectangular a flue 8 × 12 inches.
For grates 28 × 36 to 36 × 42 inches rectangular....... a flue 12 × 12 inches.
For grates 36 × 56 inches rectangular.................. a flue 12 × 16 inches.
For grates 44 × 56½ to 44 × 70½ inches rectangular..... a flue 20 × 20 inches.

For chimneys in residences or other buildings where stoves or hot-air heaters are used, or where a low rate of combustion is desired, the writer proposes this formula, which is a very satisfactory one.

$$(64) \quad K = 2A\sqrt{H},$$

where K = grate area in square feet,
A = flue area in square feet,
H = height of chimney or flue in feet.

Giving H the value 49, which is somewhere near the height of house chimneys, the following table has been calculated:

TABLE No. 29.

GRATE. Diameter, feet.	Area K, square feet.	CHIMNEY. Area A, square feet.	Diameter, inches.
1.6	2.0	0.571	10.3
1.80	2.5	0.714	11.4
1.95	3.0	0.858	12.6
2.10	3.5	1 000	13.5
2.25	4.0	1.142	14.5
2.4	4.5	1.285	15.5
2.52	5.0	1.429	16.2
2.64	5.5	1.571	17.0
2.76	6.0	1.714	17.8
2.98	7.0	2.000	19.2
3.19	8.0	2.285	20.5
3.38	9.0	2.571	21.7
3.56	10.0	2.858	22.9
3.74	11.0	3.142	24 0
3.90	12.0	3.429	25 1

The J. L. Mott Iron Works, from data gained during a long experience and close study of the subject, recommend the following table and its accompanying chimney proportions as absolutely safe.

TABLE No. 30.

Size of house in cubic feet.	RADIATING SURFACE. Square feet of direct hot water.	Square feet of steam.	Size of chimney. Inside measure. Inches.
12,000	350 to 450	250 to 300	8 × 8
15,000	450 to 550	300 to 350	8 × 12
18,000	550 to 650	350 to 450	8 × 12
24,000	850 to 1,000	500 to 600	8 × 12
30,000	1,000 to 1,200	600 to 700	12 × 12
36,000	1,200 to 1 600	700 to 900	12 × 12
42,000	1,600 to 2.000	900 to 1,200	12 × 12
60,000	2.000 to 3 000	1,200 to 1,600	12 × 16
80,000	2,500 to 4.000	1,500 to 2,000	12 × 16
100.000	3,000 to 4.500	1,800 to 2,300	16 × 16
150,000	3,500 to 5,000	2,000 to 2,600	16 × 16
200,000	4,000 to 6,000	3,000 to 4,000	16 × 20
300,000	5,000 to 8,000	4,000 to 5,000	16 × 20
400,000	8,000 to 12,000	5,000 to 6,500	20 × 20
500,000	10,000 to 14,000	6,000 to 8,000	20 × 24
700,000	13,000 to 18,000	7,500 to 9,500	24 × 24

No illustrations of house chimneys are given in this work, for the reason that, having determined the flue proportions by engineering methods, all that remains is to provide a neat exterior, which is purely architectural in its demands; but the designer should bear in mind two things: first, to be plain in the treatment of the chimney top; second, build it high enough above roofs and surrounding objects, that there will be no down drafts or wind eddies to contend with.

As in mill construction so in house construction there is no detail which plays so important a part in the comfort of the occupant as the chimney which gives the draft to the heating apparatus.

It is an appurtenance which receives but little consideration in many cases, the architect or engineer being very liable to copy some one else's proportions in preference to working out the problem again, having determined the general flue dimensions by the general rules.

House chimneys should be made as straight as possible, and if slight bends occur they should be of the same cross-sectional area as the straight part, and be made round in shape, as this shape gives much less frictional resistance than a square flue. An inside flue is much better from any engineering standpoint than one outside of the building exposed to the weather.

Ample area is especially desirable in a house chimney, that the flue may take care of the smoke of the oft kindled fire, and area must be sufficient to counteract minimum draft.

House chimneys are usually built of brick, 4 inches thick around the flue for small chimneys, and 8 to 12 inches for very large chimneys.

For house-heating a flue 8 × 12 or 8 × 8 is the smallest that should be built, not because that area is necessary, but to overcome roughness of construction and of cleaning. For large houses use not less than 12 × 16, and for steam plants use the writer's formulas and tables for anthracite coal, and elsewhere in this volume.

All other conditions being equal, the coal capacity of a chimney varies as the square root of the height, the difference of temperature * within and without the flue, and the flue area.

* Absolute temperature.

The straighter and more true the flue the more powerful the draft will be, but there are cases where even the best constructed and designed chimneys may and do smoke.

Fred. Hodgson says: "Some causes of chimneys smoking are well known and avoidable, the trouble arising perhaps from positive ill construction, having a narrow part and angle bend, or a downward portion in their conduit, which their normal draft is not sufficient to overcome.

"Others smoke because they form the shortest channel by which the air can enter the house to supply the draft to a higher chimney.

"When there are two chimneys in one room, or in rooms adjacent to each other, and the doors and windows are closed in all other rooms, the shorter will have its draft inwardly to supply the other with a current."

Sometimes the best constructed and most carefully designed chimney, with regard to the building in which it is situated, will smoke in consequence of its exit being in the immediate neighborhood of walls, hills, or trees whose situation is such as to create at times strong eddies and cross-currents.

In most cases, however, the addition of a few feet or so to the height of a chimney-shaft, supposing it to be already above the ridge of the house which it ventilates, will prove more useful than any addition of those curiously contorted and usually non-pneumatic contrivances that are so often planted on the top of a smoking chimney to cure it of its "cussedness."

Apart from the questions of normal draft and of internal regularity of construction, is the effect of wind on draft of chimneys. This varies very much with the locality of the house. The action of the wind, although, of course, always determined by physical laws, is so subtle and so delicately affected by slight causes, that there are many cases in which it is impossible to foretell it.

What is more common than to have a chimney that has been built according to the rules relating to chimneys, and which answers its purpose perfectly well, except when the wind is in one particular point of the compass.

And why does it smoke?

To be able to reply to this question is to be able to cure the defect; but how often is the difficulty regarded as insuperable?

The celebrated philosopher Count Rumford paid great attention to the subject of smoky chimneys.

He says: "Those who will take the trouble to consider the motion and properties of elastic fluids, of air, smoke, and vapor, and to examine the laws of their motions, and the necessary consequences of their being rarefied by heat, will perceive that it would be as much a miracle if smoke should not rise in a chimney—all hinderances to its ascent being removed—as that water should refuse to run in a siphon or to descend in a river.

"The whole mystery, therefore, of curing smoky chimneys is comprised in this simple direction: find out and remove those local hinderances which forcibly prevent the smoke from following its natural tendency to go up the chimney, or rather, to speak more accurately, which prevent it being forced up by the pressure of the heavier air in the room."

It is on record that Count Rumford prescribed for and cured more than 500 chimneys that had been given up as incurable, and his services were in constant demand whenever he was disposed to render them.

In Southern Italy, the land of "Master Builders," all chimneys are built over with some sort of a roof, either arched or run up to an acute angle, and so no architect ever thinks for a moment of leaving a vertical flue open at the top to receive the tremendous downpour of rain, which occasionally occurs in that sunny land.

The covering of the chimney, whatever it may be, has a number of apertures in its sides for the escape of smoke, and these openings are so constructed that when the wind strikes against them it receives an upward tendency, as the bottom or lower portions of the aperture slant upward in the same manner as a louvre board.

By this method of construction two objects are attained, the slant carries the wind upward and thereby increases the draft by suction, and it prevents the water from finding its way down the flue.

A number of mill and house chimneys have their draft improved, and that to a considerable degree, by placing a bluestone slab or iron-plate cover above the top with abundant side openings.

Another common cause for smoky chimneys that defies remedy, is the rubber weather-strips on doors, and other draft preventives, which keep all air from entering a room.

Such inlets must be allowed to exist, or special air inlets provided if we wish our chimneys to draw; again, high trees break up the wind currents as they come near a chimney and thus interfere with the draft.

BUILDING A CHIMNEY.

Brick chimneys seldom receive the care in construction that so important a structure should have.

The best and hardest bricks are usually put in the outer walls of a house, and the soft bricks, or "bats," relegated to the chimney.

This is folly, as will be appreciated by any one with a knowledge of the subject.

Good brick may be used at the top, but it is not there that there is danger of the fire eating through, but within the building where the soft brick have been used.

Tile flue-lining is rapidly coming into use and rightfully, as it makes a decidedly more efficient chimney—being as near as can be perfectly tight, and it does not absorb as much heat as a brick lining.

In topping out a house chimney there is a great difference of opinion as to what is the best mortar; one says one part of lime, and four parts cement, with sand enough to work; another says use only Portland cement throughout the whole chimney. Chimneys of "ye olden times" were laid up in simple lime mortar, and when torn down were found to be very solidly adhering masses; but the fuel used was mostly wood, and while we criticise the mason of to-day for poor lime mortar, we must bear in mind that gases generated by the combustion of coal are the principal destructors of chimneys, decomposing and destroying the life of the mortar which is employed, and causing soft brick to chip and flake, while the gases from burning wood have scarcely any effect on a well-built chimney.

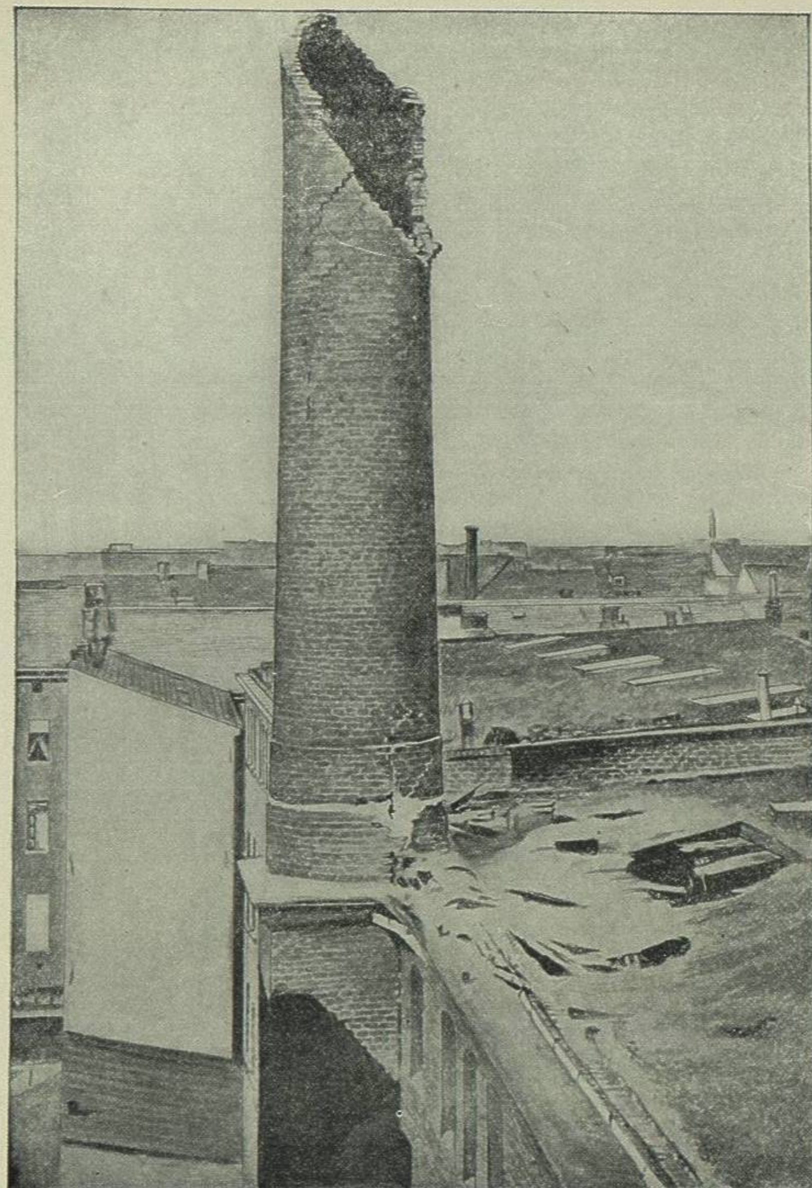
Use only the best hard brick throughout the chimney entirely; and cement mortar, and be particular to fill the joints full.

The writer has a decided preference for a severely plain chimney top, avoiding all saw-tooth effects, although the top may be drawn out a little all around, say the thickness of a brick length greater in diameter.

On top of the brickwork place a stone coping fastened with dowels of melted lead, and on top, in rainy climates, put a flat, smooth stone, supported at each corner by small blocks of stone; always keeping the opening larger than the size of flue, so as not to smother the draft.

Make the flue inside lining, if of brick, straight and smooth, taking a little extra pains in this direction.

All chimneys should be inspected annually, they should not be permitted to get choked with soot, for two reasons: first, a sooty chimney will not draw well, and it is in constant danger of firing; second, a chimney soot-lined offers special inducements for lightning to strike it.



ILLUS. No. 52.
CHIMNEY STRUCK BY LIGHTNING, JULY 29, 1890.
From *Elec. Zeits.*, Grebel.

CHAPTER X

LIGHTNING PROTECTION

OF an octagonal chimney, 260 feet 9 inches high by 14 feet diameter of flue at Narragansett Electric Lighting Company, Providence, R. I. (*Engineering Record*, 1891, p. 41), the cast-iron cap is encircled with a copper ribbon 1 inch by $\frac{3}{16}$ thick, to which are connected by a rivet and soldered joint, eight brass upright sockets, one in the centre of each panel of the cap.

To these brass sockets castings are secured, by soldered joints, $1\frac{1}{4}$-inch seamless drawn-copper tubing, which extends upward above the cap and conforms to the shape thereof, and after projecting 5 feet above the upper portion of the cap the tubes are each surmounted by a brass casting 28 inches long, tapering in section and having at its extremity a platinum point $1\frac{3}{8}$ inches long.

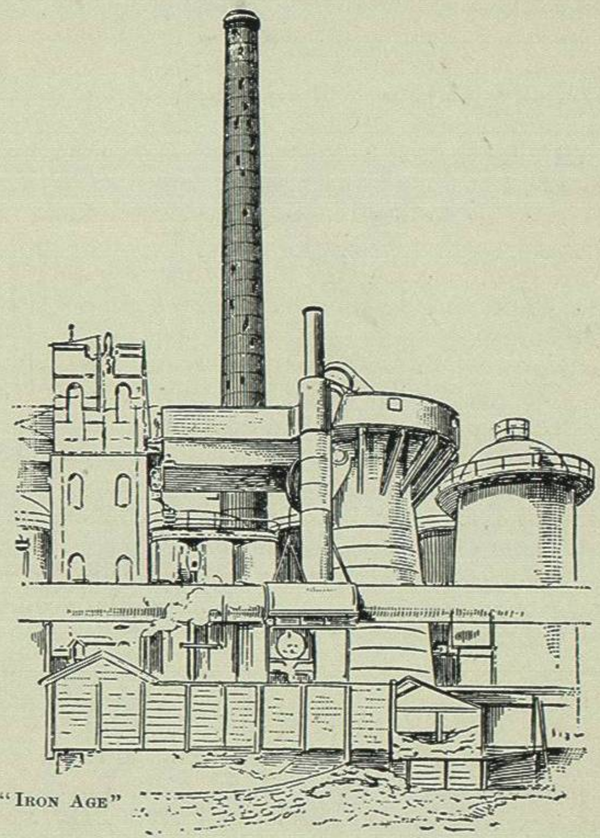
The encircling ribbon around the cap is connected to the ground ribbon by a brass casting thoroughly riveted and soldered thereto, which, as it runs down the chimney, is secured in position by brass clamps with bolts built into the brick-work as it progressed.

The lower end of the ribbon, which is $\frac{3}{16} \times 1$ inch copper, rolled in one piece, 285 feet long, terminates in a copper plate 30 inches wide by 60 inches long and $\frac{1}{16}$ inch thick, and is buried 4 feet below the natural level of the water in the soil on the premises.

The above plate is buried in a load of powdered coke, 18 inches being placed above, and 18 inches in thickness below the plate, and the whole filled with gravel.

For the protection of brick chimneys, a platinum point or tip is a most excellent one for the top of the rod, but its expense sometimes prevents its use; but for small chimneys, $50 for such a tip, about 1¼ inch high, is well spent, in fact, it makes a superior tip.

Notwithstanding its extreme hardness, the writer has seen such a point after having been struck, bent over something



"IRON AGE"

ILLUS. No. 53.

like a hook, but back close on itself. Another advantage of this metal is that it always keeps bright.

Steel or iron chimneys are never protected by rods or otherwise, as the metal in the chimney and the bolts running

down deep in the foundation are considered enough protection; the writer does not know of a single steel chimney struck by lightning which produced any bad result, except the one shown by Illustration No. 53, which shows the effect of a stroke on the blast furnace chimney of Friedrich-Wilhelms-Hütte at Muelheim a. d. Ruhr.

The chimney is said to have been perforated in twenty-three places, but strange as it may seem these openings did not materially interfere with the draft of the chimney, as the furnace continued in blast while the repairs were being made. (If natural draft had been in use the draft would have been impaired.)

For lightning protection see also descriptions of other brick chimneys.

The following extracts are made from a paper, "Protection from Lightning," published by the United States Army Weather Bureau.

"Trees near to ditches or water-courses taken by the deluge of water from the higher to the lower ground were more often struck. The same applies to building lightning-rods.

"To prevent the discharge of the fluid the conductor should be surrounded by points, though it often happens that lightning often disregards metallic surfaces altogether.

"*Erection of Rods.*—Few questions have been so thoroughly discussed from practical as well as theoretical stand-points as that of the certainty of the protection offered by properly constructed lightning rods.

"*Use a Good Iron or Copper Conductor.*—If the latter, one weighing about 6 ounces to the foot, and preferably in the form of tape. If iron is used, and it seems to be in every way as efficient as copper, have it in rod or tape form, and weighing about 35 ounces to the foot. 'A sheet of copper constitutes a conductive path for the discharge from a lightning stroke much less impeded by self-induction than the same quantity of copper in a more condensed form, whether tubular or solid.'"—Sir William Thomson.

"The nature of the locality will determine to a great degree the need of a rod. Places apart but a few miles differ greatly in the relative frequency of flashes.

"The very best ground you can get is, after all, for some flashes but a very poor one; therefore, do not imagine that you can overdo the matter in the making of a good ground. For a great many flashes an ordinary ground suffices, but the small resistance of $\frac{1}{10}$ ohm for an intense oscillatory flash may be dangerous. Bury the earth plates in damp earth or running water.

"'If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another it is best to connect them metallically. The neighborhood of small bore fusible gas-pipes and indoor gas-pipes in general should be avoided.'" (Lodge.)

"The top of the rod should be plated or in some way protected from corrosion and rust.

"Independent grounds are preferable to water and gas mains.

"Clusters of points or groups of two or three along the ridge-rod are recommended.

"Chain or linked conductors are of little use.

"*Area of Protection.*—Very little faith is to be placed in the so-called area of protection. The committee that first gave authority to this belief considered that the area protected by any one rod was one with a radius equal to twice the height of the conductor from the ground. Many lightning-rod manufacturers consider that the rod protects an area of radius equal to the height. The truth is that buildings are struck sometimes within this very area, and we now hold there is no such thing as a definite protected area.

"*Upward Motion of Stroke.*—There is no reason to doubt that the discharge takes place sometimes from earth to cloud. That is to say, that while we now consider a lightning flash as something like the discharge of a condenser through its own dielectric, made up of excessively frequent alternations, say something like 300,000 times per second, the spark or core of incandescent air may seem to have had its beginning at the earth's surface. That is to say, the air-gap breaks down first at a point near the earth.

"*Indifference of Lightning to the Path of Least Resistance.*—Nearly all treatises upon lightning, up to within very recent times, assumed that lightning always followed the path of least resistance. 'It is simply hopeless to pretend to be able,' says Lodge, 'to make the lightning conductor so much the easier path that all others are out of the question.' The path will depend largely upon the character of the flash.

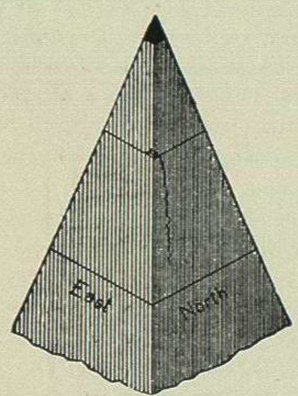
"Any part of a building, if the flash be of a certain character, may be struck, whether there is a rod on the building or not. Fortunately, these are exceptional instances. The great majority of flashes in our latitudes are not so intense but that a good lightning-rod, well earthed, makes the most natural path for the flash. We have many instances, however (not to be confounded with cases of defective rods), where edifices seemingly well protected, have been struck below the rods.

"Paradox of paradoxes, a building may be seriously damaged by lightning *without having been struck at all.* Take the famous Hotel de Ville of Brussels. This building was so well protected that scientific men pronounced it the best protected building in the world against lightning. Yet it was damaged by fire caused by a small induced spark near escaping gas. During the thunder-storm, some one flash started 'surgings' in a piece of metal not connected in any way with the protective train of metal. The building probably did not receive even a side flash. This is, therefore, a new source of danger from within, and but emphasizes the necessity of connecting metal with the rod system.

"Lightning does sometimes strike twice in the same place. Whoever studies the effects of lightning's action, especially severe cases, is almost tempted to remark that there is often but little left for the lightning to strike again. No good reason is known why a place that has once been struck may not be struck again. There are many cases on record supporting the assertion.

"It is not judicious to stand under trees during thunder-storms, in the doorway of barns, close to cattle, or near chimneys and fireplaces. On the other hand, there is not much sense in going to bed or trying to insulate one's self in feather beds. Small articles of steel, also, do not have the power to *attract* lightning, as it is popularly put, or determine the path of discharge.

"*Unnecessary Alarm.*—Just in advance of thunder-storms, whether because of the varying electrical potential of the air, or of the changing conditions of temperature, humidity, and pressure, and failure of the nervous organization to respond quickly, or to whatever cause it may be due, it cannot be denied that there is much suffering from depression, etc., at these times. It is, perhaps, possible that these sufferings may be alleviated. Apart from this, many people suffer greatly from *alarm* during the prevalence of thunder-storms, somewhat unnecessarily, we think. Grant even that the lightning is going to strike close in your vicinity. There are many flashes that are of less intensity than we imagine, discharges that the human body could withstand without permanent serious effects. Voltaire's caustic witticism 'that there are some great lords which it does not do to approach too closely, and lightning is one of these,' needs a little revision in these days of high potential oscillatory currents. Indeed, the other saying, 'Heaven has more thunders to alarm than thunderbolts to punish,' has just so much more point to it, as it is nearer the truth. *One who lives to see the lightning flash* need not concern himself much about the possibility of personal injury from that flash.



ALUMINIUM TIP OF WASHINGTON MONUMENT.

Aluminium tip weighing 100 ounces. Nearly 9 inches high, $5\frac{1}{2}$ inches square at base. Height from ground, 555 feet (169 metres).

Struck April 5, 1885, without damage. Struck June 5, 1885—Crack on north face just under top stone, extending through the block in a line nearly parallel to northeast corner.

"On June 5, 1885, the Washington Monument, at Washington, D. C., at that time the highest edifice in the world, was struck by lightning, resulting in no damage. On June 5, 1885, it was again struck, leaving a crack; a commission appointed to investigate and recommend additional protection did so with the following results and procedure: Four $\frac{1}{2}$-inch copper rods were fastened by a band to the aluminium terminal and led down the corners to the base

of the pyramidion, and then through the masonry to the columns.

"As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods $\frac{1}{2}$ and $\frac{3}{4}$ inch in diameter, respectively, furnishing 16 rods in all, connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the 11 highest horizontal joints of the masonry of the pyramidion they are connected to each other all around by other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are gold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these points in all."

Eight years have now passed since the alterations were made and the monument stands uninjured. Unquestionably, standing as it does, 555 feet high, in the centre of flat, well-watered ground, it constitutes a most dangerous *exposure* for lightning flashes. No better illustration of the value of lightning conductors can be asked.

The octagonal brick chimney of the Heywood Brothers & Wakefield Rattan Company, Wakefield, Mass., was struck by lightning March 5, 1899, the entire exterior shell being knocked away, except the cap which hung from the inner shell.

The chimney was 152 feet high, and inside a 16-foot circle at its base.

See illustration in *Power* of May, 1899.