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THE TAR IN CIGARETTE SMOKE AND ITS POSSIBLE EFFECTS

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Since the introduction of tobacco in England by Lane, in 1586, and its popularization by Raleigh, numerous objections have arisen to its use. Despite the decrees of churches, and laws enacted against the smoking of tobacco, the consumption has increased enormously, especially since the world war. In Table I the consumption of cigarettes for the years 1905, 1915, and 1925 to 1931 is compared with the number of cigars manufactured in the same period. From the table it will be observed that the consumption of cigarettes increased 14,306,437,071 or 389.4 per cent in the ten years from 1905 to 1915. In the next ten years the increase was

TABLE I

Consumption of Cigars and Cigarettes, 1905–1931 *

Year	Number of Cigars	Number of Cigarettes
1905	7,551,510,893	3,673,727,411
1915	7,561,323,265	17,980,161,482
1925	6,910,282,278	82,264,523,151
1926	6,910,956,028	92,110,213,691
1927	6,958,424,350	99,820,464,979
1928	6,788,717,161	108,715,908,651
1929	6,938,413,377	122,402,333,326
1930	6,276,960,398	123,809,553,142
1931*	5,656,062,875	114,251,752,920

* Statistics from the Annual Report of the Commissioner of Internal Revenue with the exception of those for 1931, which were obtained by adding together monthly statistics for 1931.

64,284,364,672 cigarettes, or 357.5 per cent over the consumption in 1915. The total number of cigarettes smoked in 1930 reached the enormous figure of 123,809,553,142. The years 1931 and 1932 will show a decrease, as is already indicated in the monthly reports in the *Tobacco World*.

Nicotine, next to caffeine, is the most popular and widely used alkaloid. The everyday uses of both alkaloids are mere habits,

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chemical separations were considered to be of doubtful value when dealing with such small quantities as 0.0001 mg. of chromium, an investigation was made to see if a portion of the spectrum could be found where the colored chromium compound solutions absorbed rather strongly, but where the colored iron compound solutions were completely transparent.

The light transmission characteristics of the colored iron and chromium compounds were determined by using a condensed tungsten spark in air and a Hilger rotating sector photometer in conjunction with a Hilger E1 spectrograph. The colored iron solution transmitted completely from λ 5000 towards the red end of the spectrum, but the chromium solution had an absorption maximum at approximately λ 5400.

Light transmission measurements were made at specific wave lengths in this region, using a new technic, the densities of the spectrum lines being evaluated by a Moll microphotometer. Standard curves were constructed showing the relationship between chromium content and percentage transmission at various wave lengths. The transmission by the solution prepared from the tumor ash was determined at the same wavelengths and by reference to the standard curves the amount of chromium was determined.

The chromium content of the tumor ashes varied from less than 0.001 per cent to 0.25 per cent.

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The complete details of the method employed and the results obtained will be published shortly.

not addictions as with the opiates, and the use of either can be discontinued without serious consequences.

The effects of smoking are due in a large measure to the absorption in the body of the alkaloid nicotine; as it is an alkaline substance, its continual contact with the delicate cells of the lungs during the inhalation of smoke must cause irritation. In addition to the chemical action of nicotine and other products of combustion, the thermal and mechanical phases of the smoking habit modify its effects. All of these are, in turn, made worse by disease conditions already present in the mouth and the body. The chemical and thermal effects are also modified by several other factors, as the age of acquiring the smoking habit, the grade of tobacco, the manner in which it is smoked, and the amount used.

Some of the nicotine in tobacco is present as a free alkaloid, readily volatile and easily extracted with petrolic ether; the remainder is combined as salts with organic acids (Garner). During smoking, these salts are dissociated, a portion of the nicotine is burned, and a part passes into the smoke. Moist tobacco gives off more nicotine during combustion than the drier tobacco.

The so-called denicotinized tobacco products still contain about 50 per cent of the nicotine (Van Leeuwen; Bailey), and large amounts of this tobacco are likely to be smoked under the false assumption that the harmful element is removed. Nicotinin, nicotein, and nicotellin have been isolated by Pictet and Rotschy from tobacco, but in very small amount. Lehmann, Kissling, and Garner demonstrated that one-seventh to one-third of the nicotine of tobacco may be recovered from the smoke. Van Leeuwen reported that the common distinction between so-called "mild" and "strong" cigars is no index to the amount of nicotine that may pass into the smoke. The absorption of nicotine is responsible for the untoward effects of the neophyte's first pack of cigarettes or first cigar.

The nicotine content of tobacco varies; that of pipe tobacco from 1.25 to 2.8 per cent; of cigars from 0.91 to 1.9 per cent; of cigarettes from 0.43 to 3.34 per cent (Thurston; Bailey). If a cigarette is smoked rapidly, the nicotine content of the main stream of smoke, drawn through the cigarette, is increased. Bogen found that when the duration of combustion was five minutes, with continuous suction, the nicotine content of the main stream was 2.5 mg.; when combustion was complete in two minutes, the

nicotine content was 6.5 mg. Not only the rapidity of smoking, but the amount of moisture, the thickness of the cigarette, and the closeness of the packing are factors in determining the amount of nicotine in the smoke.

Both the smoke that is exhaled and the smoke arising from the burning end contain nicotine, as has been demonstrated by Lehmann in the air of a room in which tobacco was being consumed. Asherson asserts that 6 to 8 mg. of nicotine reach the mouth from a cigarette smoked in the usual way. Dixon aspirated smoke from one cigarette weighing one gram and found that the solvents absorbed 3 mg. of nicotine. Winterstein and Aronson state that 13 to 15 per cent of the nicotine content of cigars and cigarettes is absorbed by the organism. If a smoker were to smoke twenty cigarettes a day he would receive 0.60 mg. (Dixon), an amount which, if it were all absorbed, would cause definite physiological effects. Fortunately not all the nicotine is absorbed. The fatal dose for man is 60 to 120 mg.

The continued use of tobacco apparently creates a tolerance for nicotine and the products of combustion; otherwise cases of poisoning would not be limited to the beginner. The nitrogen of the smoke may run as high as 43 per cent of the total nitrogen: the nicotine nitrogen may run as high as 17.68 per cent and the ammonia nitrogen as high as 63.2 per cent of the total nitrogen of the smoke (Gawrilow and Koperina).

Zebrowski, in order to show the effect of tobacco smoke upon the blood vessels of animals, had them breathe tobacco smoke in a special apparatus, while other animals received injections of the soluble components of the smoke in the veins. One group of rabbits was given 0.5 per cent nicotine solution. Thickenings were found upon the intima of the descending aorta in three out of five rabbits which received nicotine injections. Similar transformations were found in rabbits which had received adrenalin hydrochloride in 1 : 1000 solution. One rabbit showed considerable transformation in the initial portion or the beginning of the aorta, while in the second rabbit the adrenalin did not cause such changes.

Mertens exposed mice to the smoke of cigarettes. He reported suppuration in the trachea, bronchi, and lungs. In one case the mucosa was transformed into a layer of pavement epithelium with several rows of cells.

Some investigators, as Ratner, Vas, and Heubel, considered the nicotine the sole component of tobacco smoke. Vohl attrib-

uted the deleterious effect of the smoke to pyridin and picolin bases. Johnson, in a clinical study of tobacco smoking in 150 patients, concluded that "the effect of smoking is chiefly local, exerted principally on the pharynx." Webb recognized a cigarette bronchitis in the examination of 3,000 men in the army. Philippson points to various organic carcinomata which might be produced by nicotine. He places the chemical factor so far above the purely mechanical factor that he prefers to speak of "nicotine cancer" rather than pipe smoker's cancer.

Several authors are of the opinion that nicotine plays a certain rôle in the etiology of cirrhosis of the liver (v. Noorden; Guillan and Gy; Adler). As nicotine is evacuated through the bladder, it could exert an irritation of the mucosa.

Pyridin must also be taken into consideration as a potent factor in causing irritation. Stoeber and Wacker demonstrated that epithelial proliferation could be evoked in animals by injections of pyridin in olive oil. Hamilton says that pyridins have a curious effect on the skin similar to that which has been described in English briquette factories as a result of the handling of tarry substances. The skin is raw and sensitive as if from sunburn. The suffering is most severe after washing the face, hands, and forearms and going into the open air. The action of pyridin bases is somewhat similar to that of nicotine but with important differences (Lee). Pyridin is a strong local irritant with a low toxicity. It produces dyspneic, then shallow respiration. Brunton and Tunnicliffe refer the effects mainly to sensory paralysis. Large doses arrest the heart action.

With slow, intermittent combustion the cigarette yields a small amount of carbon monoxide in the main stream of smoke. In eleven minutes the yield of carbon monoxide was 0.26 per cent of the weight of the tobacco and paper burned (McNally). With more rapid combustion (five minutes) this is increased to 1.30 per cent. Tobacco smoke contains 80 c.c. of carbon monoxide to the gram of tobacco smoked (Thompson; Fleig). The smoke diluted with air, as it reaches the mouth of the smoker, may contain 7.2 to 25 parts of carbon monoxide (Baumberger, Perry, and Martin) in 10,000 parts of air, which is a dangerous amount to be consumed over a period of one hour. Fortunately the concentration of the air breathed does not reach this high figure, and the lungs are ventilated before there is time for absorption. When the concentration of the air becomes 9 per 10,000 parts of air, headache

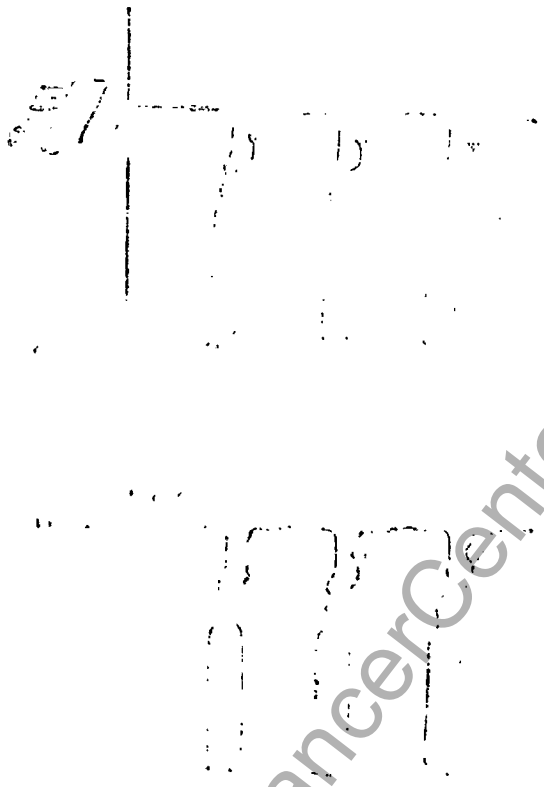
and nausea are induced (Henderson and Haggard). The U. S. Bureau of Mines examined the air in a confined space after intensive smoking, and found that the carbon monoxide concentration of the air of the room did not increase beyond 0.01 per cent; the maximum blood concentration did not rise above 5 per cent, quantities that are considered negligible. Carbon monoxide as inhaled in the smoke of cigarettes cannot, therefore, be considered as an irritant.

Since this investigation has to do with the smoke of tobacco in the form of cigarettes, it will include the water-soluble components as well as the tar-like substances. In an effort to obtain products of smoke as much like those taken into the system during the process of smoking as possible, the smoke from six cigarettes in a holder was passed through a series of Drechsel wash bottles (Fig. 1). Both intermittent and continuous suction were used. No attempt was made to collect such gases as carbon monoxide and carbon dioxide.

The amount of tar separating increased rapidly in the last three quarters of an inch of the cigarette. The process of smoking is like a volatile distillation, the moisture, as steam, carrying along the volatile products, some of which accumulate in the cooler portion of the cigarette, which happens to be the last half inch in the holder. The water extracts contained (in addition to the tars and tar oils) cyanides, carbonates, nitrates, arsenic, ammonia, hydrogen sulphide, methyl alcohol, fatty acids, formaldehyde, acrylic aldehyde, nicotine, pyridin, picoline, lutidin, collidine, and phenolic bodies. Loebisch mentions the presence of creosote. Ammonia, which is an irritant, is present in mere traces, 0.1 mg. per cigarette. It is never recognized in the smoke by its odor (1/20 vol. of NH_3 per 1,000 parts of air imparts a strong odor).

Warburg believes that nicotine is not wholly responsible for the symptoms resulting from excessive smoking, that some other substance plays a rôle. This substance, I believe, is the tarry material separating from the smoke. Methyl alcohol discovered in tobacco smoke by Neuberg, formaldehyde by Trillat, and hydrocyanic acid by Vogel, may intensify the irritant action of the tar and tar oils on the delicate mucous membranes of the respiratory tract. Lehmann and Gundermann claim that the hydrocyanic acid in the smoke of a cigar amounts to 0.002 to 0.5 mg. and is of no significance. Where there is an inflammation of the mucous membrane, continually irritated by the products of smoking, the

regeneration processes are disturbed, and there is a predisposition to cancer in the sense of the regeneration theory of Fischer-Wasels.



FIGS. 1 AND 2. SHOWING CIGARETTES IN HOLDER, DRECHSEL WASH BOTTLES, AND THERMOMETERS TO SHOW TEMPERATURES OF SMOKE AT VARIOUS DISTANCES FROM HOLDER

The mechanical factor in the smoking of cigarettes is not of great importance, as the majority of men and women do not use cigarette holders. With cigars and pipes, however, a roughened holder or pipe stem may play an important part in the irritation of the lip.

The thermal factor is much more important in the smoking of

cigarettes, as the smoke of a cigarette may reach 190° C., if it is smoked rapidly down to the end, in a holder. The temperature of the smoke for the first 3.5 cm. remains around 27.2° C., this figure gradually rising to 52° C. if the cigarette is smoked to within 0.5 cm. of the end (see Table II and Fig. 2). With rapid smoking the smoke in a holder may reach 52° C. within two minutes. With the average time for smoking a cigarette, nine minutes, the temperature of the smoke remains around 30.2° until the last 2.5 cm., when it rapidly rises to 46.0° C. The accompanying table shows the temperature of smoke at varying distances from the butt end of the cigarette. The rapidity of smoking is a very important factor, as can be seen from the table. D was smoked in eleven minutes, A in nine, C in five, and B in two minutes.

TABLE II

Temperature of Smoke at Varying Distances from Butt End of Cigarette

Brand	Initial Temp	3 cm. smoked	3.5 cm.	5 cm.	6 cm.	6.5 cm.
A	27.2°	30.0°	30.2°	31°	42°	55°
B	27.0°	30.2°	30.2°	36°	55°	110°
C	27.4°	30.0°	30.6°	31°	35°	78°
D	29.2°	30.4°	30.2°	30.8°	36.2°	46.0°

The burning end of the cigarette may reach a temperature of 280 to 300°. Those using a holder and burning to the extreme end can obtain a temperature inside the mouth of 36.8° C. and on the outside of the holder of 56 degrees. Fortunately the cheapness of the product does not necessitate smoking to the very end, and the

TABLE III

Temperature of Smoke Held in Mouth

Subject	Last 2 cm.	1 cm.	½ cm.
T	34	35.4	—
H. W.	35	35.2	36.2
B	35	35.2	36.8
W. D.	34.2	35.2	35.0

majority of cigarette smokers do not use holders. The temperature of the smoke in the mouth is shown in Table III. Cooper reports that the temperature of tobacco in both wooden and clay pipes may range from 370 to 700° C.

With the thermometer at a distance of 2 cm. from the end of the cigarette, with three minutes' continuous smoking, the tem-

perature will vary from 70° to 165° C.; at a distance of 0.5 cm. the temperature was 190° C. With the thermometer 5 cm. away from the cigarette the temperature will vary from 65° to 92° C.

Using an apparatus cooled by water (Fig. 3), I imitated smoking by intermittent suction, recording the results in Table IV. The absorption apparatus was weighed with the distillate obtained from the intermittent smoking of a single cigarette. This was dried in an oven at 105° C., the tarry material recorded as residue. The volatile matter varied from 7.92 per cent to 21.12 per cent, the

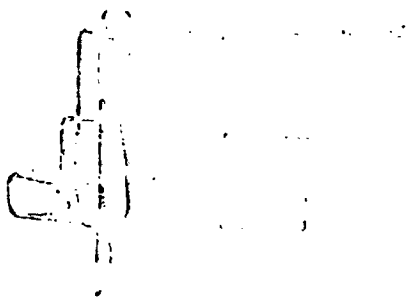


FIG. 3. WATER-COOLED APPARATUS FOR INTERMITTENT SUCTION

average of 33 popular brands being 14.96 per cent. The tarry residue varied between 4.84 per cent and 15.29 per cent, the average being 10.41 per cent. The average weight of a cigarette for the 33 brands used in this investigation was 1.0911 gm. In Table V are given the results with continuous suction during the same period, showing a slight increase in both the volatile and tarry residue. For comparison the moisture content and the volatile matter collected from cigarettes of the same package are also given.

When the absorption apparatus was used without refrigeration, the volatile matter with cigarette No. 15 was 10.39 per cent and the tarry residue was 7.08 per cent. The exhaled smoke was passed through the same type of absorption tube, the volatile matter was 32.75 per cent and the residue was 2.97 per cent. Table VI shows the lung and mouth absorption for several brands,

for comparison with Table V. With the absorption or retention in the system of 6.56 to 11.58 per cent of tarry material, there must be absorbed at the same time considerable amounts of pyridin bases, nicotine, cyanide, and aldehydes.

Bergerhoff explains the effect of the different irritants under consideration in the oral cavity as follows. The habitual smoker

TABLE IV

Results of Experiments with Intermittent Suction

Brand	Volatile matter	Residue
1	11.51%	9.72%
2	13.17%	10.14%
3	12.33%	8.20%
4	14.0%	7.58%
5	10.79%	11.11%
6	14.53%	6.69%
7	11.62%	7.80%
8	13.97%	13.44%
9	9.51%	13.85%
10	14.07%	12.71%
11	16.95%	7.14%
12	16.20%	8.83%
13	19.15%	10.82%
14	15.55%	8.12%
15	11.83%	14.55%
16	15.98%	12.28%
17	13.53%	9.19%
18	10.07%	10.75%
19	21.12%	10.84%
20	12.96%	5.45%
21	26.05%	8.09%
22	11.61%	9.38%
23	14.14%	12.42%
24	19.39%	6.55%
25	11.57%	10.83%
26	13.24%	10.67%
27	10.70%	15.16%
28	15.89%	12.41%
29	16.65%	12.68%
30	7.92%	15.29%
31	18.15%	4.84%
32	17.82%	12.55%
33	11.56%	7.66%
	19.78%	5.76%

becomes accustomed to the biting sensation after the contact of tar oils with the mucous membranes of the mouth, the secretion of saliva is not stimulated, and the irritants continue to exert their action. Brosch was the first one to produce atypical epithelial proliferation by the application of tobacco juice. Wacker and Schmincke in 1911 reported experiments on the ear of the rabbit

in which proliferations of an extensive nature, and of a close histologic resemblance to squamous-cell epithelioma, were produced with tobacco tar. They determined that only lipoid soluble substances produced epithelial proliferations. In 1923 Hoffman, Schreus and Zurhelle succeeded in producing only a hyperkeratosis on the skin of mice. The hair fell out and grew in again when the application of tar ceased. Helwig used the residue found in bowls of briar pipes, but as most of his mice died from too strong solution he tried an ethereal extract and reported the development of suggestive lesions in about two weeks.

TABLE V

Results of Experiments with Continuous Suction

Brand	Moisture	Volatile	Tarry Residue
33	12.71%	17.73%	8.60%
15	14.15	13.87	10.61
32	18.87	18.33	7.53
13	8.38	17.73	5.20

TABLE VI

Lung and Mouth Absorption of Tar for Various Brands of Cigarettes

Brand	Volatile	Residue	Absorbed or Retained in Body
15	32.75%	2.97%	7.64% to 11.58%
13	11.43%	4.20%	6.56%
18	18.56%	1.97%	8.10%
14	8.20%	13.46%	10.36%
29	58.56%	1.02%	11.66%
33	15.64%	2.35%	7.17%

H. Schaer, in the examination of 237 esophaguses, chiefly from men, found leukoplakia in 67 per cent of all of the cases. This occurred more often in men than in women. Leukoplakia, according to Haase, is a disease of males, women being affected in only 1.99 per cent of the cases. According to Hoffman, cancer of the esophagus increased from 1.0 per 100,000 in 1915 to 1.7 in 1922, fell to 1.4 in 1924, rose to 1.8 in 1926, but declined to 1.7 in 1927. For cancer of the lungs, he gives the death rate as 0.7 per 100,000 in 1915, 1.1 in 1920, 1.6 in 1924, and 1.9, the maximum figure, in 1927. Comparing the enormous consumption of cigarettes in 1925–1931 with the increase in pulmonary cancer, one is certainly led to believe that cigarette smoking is an important factor in the increase of

cancer of the lungs. In England during the period 1901-1910 the death rate was 1 per 100,000, increasing to 2.3 per 100,000 in 1927.

The more frequent occurrence of ulcer and carcinoma in smokers can be attributed to the irritant action of the chemical substances mentioned. In Holland, where tobacco is used more extensively than anywhere else in Europe, the death rate for cancer of the stomach is 553. In England it is 333. Cancer of the stomach is much more prevalent in the male than in the female.

Bossi quotes the experiments of Adler, Jouse, Hosel and Papadia with tobacco smoke and reports the results of having animals inhale the smoke of cigarettes, after the method of Bufalini. Some of his rabbits developed a glycosuria, which in my opinion came from the carbon monoxide absorbed. Roffo, from his experiments, believes that the water-soluble constituents of smoke have more carcinogenic properties than the alkaloid nicotine.

Fürbringer claims that the inhaler absorbs as much as eight times the amount of nicotine absorbed by mouth smokers. The word "inhaler" is generally used to designate a person who exhales smoke through the nostrils, and not in the sense that the suction action of the lung during smoking makes every one an inhaler, as a popular brand of cigarette advertizes. Woglom, in discussing experimental tar (from coal) cancer, says: "There are almost as many explanations of the way in which tar produces a malignant growth as there are investigators."

The water-soluble products from the smoke of 100 cigarettes were made up to 100 c.c., and 0.1 c.c. was given daily as a spray per mouth to 6 half-grown rats. To another 6 rats the tar collected was applied at the back of the left ear; 6 other rats had the tar applied to a spot shaved on the back, about 1 inch in diameter, 6 others had tar applied to the tongue and buccal surfaces. Two rats were kept as controls. The tar was soluble in chloroform, petroleum ether, and benzol, but was insoluble in ethylic ether.

Since 3 of the rats having the tar applied to the back died on the eighth day from nicotine poisoning, the amount of tar was reduced. On the fifty-second day one control rat died. On the seventy-second day a rat died having two areas of inflammation on the tongue about the size of a grain of wheat, caused by encysted *Trichinella spiralis*. On the ninety-seventh day a rat died which had received tar per mouth. On the hundred and tenth day three rats having tar on the back became ill and lost weight, and it

was necessary to withdraw the tar. The hair grew in again after the application of the tar ceased. The gross examination of the organs of the rats dying during the experiment did not show anything of note. All of the rats grew a coarser hair than the controls. The experimental animals did not grow as rapidly as the control animals.

Conclusions

1. The tar of cigarette smoke contains nicotine, phenolic bodies, pyridine bases, and ammonia, irritants which could account for "cigarette cough," the chronic bronchitis of the cigarette smoker, the leukoplakia in heavy smokers, and the recorded increase of cancer of the lung.

2. The temperature is not an important factor unless the cigarette is burned down to the last centimeter, when the hot smoke becomes more irritating.

3. With a tarry residue of 4.84 to 15.29 per cent, a definite risk attaches to the smoking of a cigarette, especially since 6.56 to 11.58 per cent may be absorbed or retained in the body.

4. Cigarettes should not be smoked too short, as the last two centimeters retain most of the tar and other products of incomplete combustion.

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