

The History of Skunk Defensive Secretion Research

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Abstract: The striped skunk (*Mephitis mephitis*) is widely known for the highly odoriferous defensive secretion it uses to repel predators. Chemists have sporadically investigated the chemical composition of this secretion for many years. In this research, a number of chemicals have been incorrectly attributed to this secretion and the errors incorporated into the chemical literature. The major component in skunk spray was erroneously believed to be 1-butanethiol, until it was later shown that the actual compound was (*E*)-2-butene-1-thiol. More recently, two studies identified the third major compound in the secretion as either (*E*)-2-butenyl methyl disulfide or (*E*)-2-butenyl propyl sulfide. These structural assignments were incorrect and the compound was later shown to be (*E*)-2-butenyl thioacetate. Two investigations have reported chemicals that could not be confirmed in a later study, so these compounds may have been artifacts produced during isolation or analysis. The striped skunk's secretion is similar to, but different from, the defensive secretions of two other skunk species, the spotted skunk (*Spilogale gracilis*) and the hog-nosed skunk (*Conepatus mesoleucus*).

Folklore asserts that tomato juice will neutralize the odor of skunk spray, but human olfactory fatigue can explain the apparent disappearance of the odor on sprayed pets. The odoriferous thiols in skunk spray can easily be neutralized by oxidation to sulfonic acids.

Introduction

Skunks and their defensive secretion have both fascinated and repelled natural product chemists. The chemicals secreted by the members of the *mephatinae*, a New World subfamily of the weasel family (*Mustelidae*), are so obnoxious that few chemists have been willing to work with them. On the other hand, once researchers published the identity of these components, the purported identities were cited far and wide in the popular and chemical literature. This led to several incorrect structural identifications persisting in the literature for years because few chemists were interested in reinvestigating the chemicals in these secretions.

Six species of skunks are found in North America: the striped skunk, *Mephitis mephitis*; the hooded skunk, *M. macroura*; two species of hog-nosed skunks, *Conepatus mesoleucus* and *C. leuconotus*; and two species of spotted skunks, *Spilogale putorius* and *S. gracilis*. Spotted skunks were previously considered one species (*S. putorius*), but have recently been divided into two species, *S. putorius* in the eastern United States and *S. gracilis* in the western U.S. All skunk species are known for their potent means of chemical defense: the spraying of a repulsive-smelling liquid from their anal glands. Research on this secretion has been focused for the most part on the most common member of this group, the striped skunk (Figure 1). In this review, the term "skunk" refers to this species, unless otherwise specified.

Skunk defensive secretion is frequently referred to as either *skunk spray* or *skunk musk*. This secretion is stored in two glands (anal sacs) leading to nipples situated just outside the anal opening. When attacked or surprised, a skunk lifts its tail and will eject this secretion a distance of up to about 3 meters (Figure 2). At high concentrations it can cause nausea and retching in humans and, like tear gas, it is a strong lachrymator if it comes in contact with the eyes. At lower concentrations it is highly repellant and can be detected by humans at extremely

low concentrations. In 1896, Aldrich showed it could be detected at 10 ppb [1].

High concentrations of skunk spray can be toxic. Hydrogen sulfide is very toxic to humans; methanethiol at concentrations of 1 part per 100 in air will kill rats. In 1896, Aldrich made the following speculation, indicating that the toxic properties of compounds in skunk spray might result in death [1]: "The substance is a powerful anaesthetic, and has also been used as an antispasmodic. When inhaled without the admixture of a large amount of air the victim loses consciousness, the temperature falls, the pulse slackens, and, if the inhalation were prolonged, the results would doubtless prove fatal."

The anesthetic properties of the secretion referred to by Aldrich above, stems from an 1881 report by W. B. Conway, M.D. at the Virginia Agricultural and Mechanical College in Blacksburg, Virginia [2].

"Some time during the summer of 1879, two or three boys [students at the above college], secured a two-ounce bottle of the *perfume* from the skunk or pole-cat (*Mephitis Americanae*), and concluded to play a trick upon one of their school mates; entering his room, they held him, and administered the above nauseous fluid (in its most concentrated form), by inhalation. I could not ascertain what amount was administered. However, when I reached him I found the following symptoms: A total unconsciousness, relaxation of the muscular system, extremities cool, pupils natural, breathing normal, pulse 65, temperature 94; in which condition he remained for one hour."

In the hour it took to revive the patient, the doctor "administered small quantities of whisky at short intervals *per orem*, with some difficulty getting him to swallow." The victim of this prank was reported to have a slight headache on awakening that "passed off after a good night's sleep."

Many of the chemicals that have been identified in skunk spray are thiols. In the older chemical literature these compounds were called mercaptans, a name derived from the



Figure 1. The striped skunk, *mephitis mephitis* (photo by W. F. Wood).



Figure 2. The striped skunk lifting its tail before spraying (photo by W. F. Wood).



Figure 3. Sample of the defensive secretion from the striped skunk (photo by W. F. Wood).

fact that these compounds form compounds with mercury. In this review, modern chemical nomenclature terms are used except in quotations of original literature. As an example, the names “normal butyl mercaptan” or “*n*-butyl mercaptan” used in the original literature are replaced with “1-butanethiol.” A glossary of old and new names is included at the end of this review.

Chemicals from the Striped Skunk (*Mephitis mephitis*)

The first report in the chemical literature on skunk spray was in 1862 by a Dr. Swarts working with Wöhler in Germany [3]. They had obtained a sample of the secretion from a friend in New York. Swarts analyzed the yellow oil and found that it consisted of a colorless fraction boiling between 105 and 110 °C, a higher boiling yellow fraction boiling between 195 and 200 °C, and a nitrogenous basic compound in the residue after distillation. In another experiment Swarts steam-distilled the secretion and found the water-insoluble part of the distillate to be rich in sulfur.

In 1879 another German, Dr. O. Löw next reported work on skunk spray [4]. He confirmed Swarts’ findings that it contained sulfur compounds and a nitrogenous base. His major problem in completing the research was not his chemical expertise, but the reactions of his companions and co-workers. Löw’s experience was reported in a letter, part of which was included in a later report on skunk spray by Aldrich [1].

“On an expedition through Texas in 1872 I had frequent opportunity to collect a sufficient quantity of this secretion to establish its chemical constitution, but all my companions protested against it, declaring the odour which clung to me to be unbearable. On my return to New York City I started a few chemical tests, with the little I had collected, when the whole college rose in revolt, shouting, ‘A skunk, a skunk is here!’ I had to abandon the investigation.”

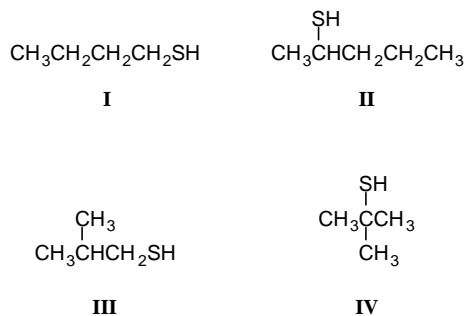
Thomas Aldrich, working in the Laboratory for Physiological Chemistry at The Johns Hopkins University, next investigated skunk secretion and reported his studies in 1896 and 1897 [1, 5]. He had a plentiful supply of skunk anal sacs from sources primarily in Maine, and stated he received some of these samples within 12 hours of collection. The amount of secretion in these glands varied, with a maximum of about 5 mL. He described it as follows, “the secretion is a clear, limpid fluid, of golden-yellow or light-amber colour, of a characteristic, penetrating, and most powerful odour, and having a specific gravity, at ordinary temperature, less than water (0.939).” See Figure 3.

In his first study, Aldrich distilled the secretion and found two major volatile fractions, one boiling from 100 to 130 °C and another from 130 to 150 °C [1]. The low boiling fraction was further divided into fractions; most of the material distilled between 100 and 110 °C. In order to identify the thiol(s) in the low-boiling fraction, he looked at known thiols. On the basis of their boiling points he excluded several low molecular weight thiols: methanethiol (bp 6 °C), ethanethiol (bp 36 °C), 1-propanethiol (bp 67 °C), and 2-propanethiol (bp 57–60 °C). As part of his study, Aldrich prepared 3-methyl-1-butanethiol and determined its boiling range as 115–120 °C. Because the boiling range of this 5-carbon compound is higher than that of the major fraction (100–110 °C), Aldrich focused his study on the 4-carbon thiol, 1-butanethiol, which has a

boiling point of 97 °C. He speculated that the fraction distilling between 100 and 110 °C could possibly be 1-butanethiol, if it were contaminated by a small quantity of a higher-boiling compound.

Elemental analysis for sulfur in the lowest boiling fraction gives results that are close to what would be expected for 1-butanethiol (or an isomer). The calculated value for %S in C₄H₉SH is 35.55%, and Aldrich found 35.37% and 34.98%, values too low to make a positive identification of C₄H₉SH.

Aldrich was unable to perform carbon and hydrogen elemental analyses directly on the lowest boiling fraction due to decomposition of the thiol during the analysis. To overcome this problem, he prepared lead and mercury derivatives of the thiol in the lowest boiling fraction. Here too, the carbon and hydrogen elemental analyses of these derivatives were slightly different than would be expected for C₄H₉SH. In his report he stated, "The results of these analyses are sufficiently near the theoretical figures when considered with the boiling point to convince, I think, the most skeptical that the greater part of this fraction contains one of the butyl mercaptans." There are three other thiols with the same molecular formula as 1-butanethiol (**I**): 2-butanethiol (**II**), 2-methyl-1-propanethiol (**III**) and 2-methyl-2-propanethiol (**IV**). Of these compounds, Aldrich attempted to synthesize 2-methyl-1-propanethiol, but did not succeed.



Because Aldrich's boiling point and elemental analysis values were very close to expected values, he speculated that an impurity could be responsible for the difference [1].

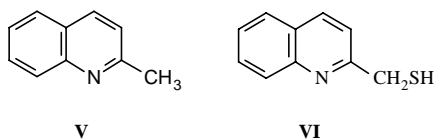
"Primary normal butyl mercaptan is given as boiling at 97 °C. The boiling point of the fraction boiling between 100° and 110 °C could be easily explained if we assume the presence in small quantity of some higher boiling body. This assumption would also explain in general the analytical results. I am inclined to believe in the presence of a higher mercaptan (say amyl mercaptan [3-methyl-1-butanethiol]) rather than a sulphide."

In his explanation of the difference in elemental analysis of his compound from that expected for 1-butanethiol, Aldrich never indicated that he considered compounds with double bonds or rings as a possibility.

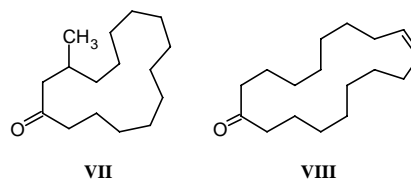
The long-held belief that skunk secretion contains 1-butanethiol (butyl mercaptan) certainly owes its source to Aldrich's 1896 publication [1]. Aldrich was very careful not to claim a positive identification of 1-butanethiol, but did say the compound could be 1-butanethiol or an isomer, if one took into account impurities in his samples. He did, however, use the following names to describe the elemental analysis of the derivative of the thiol that boiled between 100 and 110 °C: lead butyl mercaptide, (C₄H₉S)₂Pb; and mercuric butyl

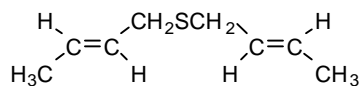
mercaptide, (C₄H₉S)₂Hg. He then stated it was likely the secretion "contained one of the butyl mercaptans." He reiterated this in his second publication on this secretion, stating this part of the secretion "is a mixture of higher mercaptans, containing among others (still undetermined) normal butyl mercaptan" [5]. The many references to 1-butanethiol in Aldrich's articles certainly must have led others into believing this compound had been positively identified in skunk spray. This misconception was incorporated into the chemical literature and persisted for many years. A 1978 review by Andersen and Bernstein on this topic describes the myth that skunk spray is primarily 1-butanethiol as, "well established as part of the folklore of organic chemistry by the 1940s and maybe earlier" [6]. For example, when Stevens reported on an additional compound from skunk spray in 1945, he stated that Aldrich showed "that the principal odoriferous material is *n*-butyl mercaptan" [7]. The seventh edition of the *Merck Index* (1960) under "*n*-butyl mercaptan" says it "occurs in skunk fluid" and, in the entry, "Skunk Oil," it cites Stevens' work and reiterates that skunk spray contains *n*-butyl mercaptan (1-butanethiol).

In 1897, Aldrich and Jones published a second report on skunk defensive secretion [5]. In this study they identified 2-methylquinoline (**V**), a nitrogenous base that was presumably the one that had previously been reported by Swarts [3] and Löw [4]. Aldrich and Jones based their identification on a number of derivatives prepared from the skunk's compound and compared them to the same derivatives of a synthetic sample of 2-methylquinoline. Andersen, et al. [8] and Wood [9] in later studies reconfirmed the presence of this compound in skunk spray. Aldrich also detected a second basic compound that was less volatile in the steam distillation by which he isolated 2-methylquinoline. He did not identify this second alkaloid, but did say, "It may be stated in passing that the less volatile body differs from the more volatile in containing sulphur." Likely this was 2-quinolinemethanethiol (**VI**), identified 93 years later by Wood [9].



In 1945, Stevens made a brief foray into the field of skunk research while searching for new animal musks, specifically large-ring ketones that could be used as perfume bases [7]. Animal musks have been an ingredient in high quality perfumes for many years. About 20 years before Steven's study on skunk musk, Ruzicka had isolated and identified muscone (**VII**) from the musk deer [10, 11] and civetone (**VIII**) from the African civet [12, 13]. Both of these compounds are large-ring ketones. Stevens failed to find any large ring ketones, but did isolate bis[(*E*)-2-butenyl] sulfide (**IX**).

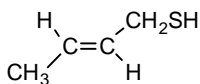




IX

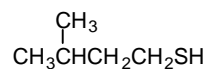
Stevens noted that the secretion was “repulsive in odor,” which may have kept him from working on it in a timely fashion. The experimental procedure indicates that after collection, the native secretion separated into two layers “after several months” of storage. The sample was next treated for several days with mercuric chloride to remove the thiols. After removal of the mercury salts, the solution was stored for “considerable time” before the solvent was removed. An initial vacuum distillation was followed by extraction with 7% HCl and 10% “alkali” to remove impurities. Finally, two successive vacuum distillations were used to isolate the bis[(*E*)-2-butenyl] sulfide. Stevens started with 210 g of secretion and isolated 4.5 g of the sulfide so, assuming none was lost, the initial secretion should have contained at least 2% of this compound. Later work on freshly collected skunk spray could not confirm this compound even as a minor component [9]. The extensive and harsh conditions used in Stevens’ isolation procedure may have produced this compound.

In 1975, 79 years after Aldrich’s investigation, Kenneth Andersen and David Bernstein at the University of New Hampshire showed that 1-butanethiol (**I**) is not a major component of skunk spray [14]. This study was done using the volatile material obtained from a vacuum distillation of the secretion. The major volatile compound is the unsaturated (*E*)-2-butene-1-thiol (**X**). It was identified by comparison of IR and ¹H-NMR spectra of the skunk-produced compound to those of a synthetic sample. Andersen and Bernstein later re-examined Aldrich’s elemental analyses of derivatives prepared from the lowest boiling fraction of skunk spray [6]. For many of Aldrich’s derivatives, the percentages of carbon and hydrogen are within the experimental values expected for (*E*)-2-butene-1-thiol. Thus, Aldrich had certainly isolated a pure sample of this compound.



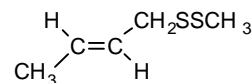
X

Andersen and Bernstein similarly used IR and NMR spectroscopy in their 1975 study to identify a second volatile thiol from skunk spray, 3-methyl-1-butanethiol (**XI**). Interestingly, in 1896 Aldrich had prepared 3-methyl-1-butanethiol as part of his first study on skunk spray and speculated it may have been a reason for the faulty elemental analysis [1]. He said his synthetic compound had the same boiling point, appearance, and odor of a fraction of skunk secretion with the same boiling point. Alas, he never made a positive identification of this compound by elemental analysis or making derivatives.



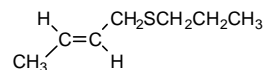
XI

The third-most-abundant volatile compound Anderson and Bernstein found in the secretion was identified as (*E*)-2-butenyl methyl disulfide (**XII**) [14]. They synthesized this compound from *S*-methyl thiophthalimide and (*E*)-2-butene-1-thiol in refluxing benzene. This compound and the one from skunk spray were reported to have identical NMR and IR spectra; 15 years later, however, this structural assignment was shown to be incorrect [9].

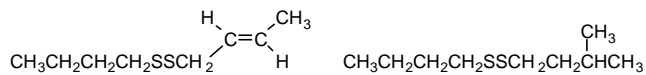


XII

In 1982, Andersen and co-workers reported their continued research on skunk defensive secretion using gas chromatography–mass spectrometry (GC-MS) to identify many new major and minor (less than 1%) constituents in skunk spray [8]. This study confirmed the identifications of (*E*)-2-butene-1-thiol and 3-methyl-1-butanethiol (66%, coeluted), but was unable to confirm the third major component of their first study, (*E*)-2-butenyl methyl disulfide. In this second study, (*E*)-2-butenyl propyl sulfide (**XIII**) was reported as the third-most-abundant compound (7%). This compound was identified by analysis of its mass spectral fragmentation pattern, however, like the third major compound of the previous study, it too was an incorrect structural assignment [9]. Other major compounds tentatively identified from mass spectral fragmentation patterns were two disulfides (7%) that coeluted, butyl (*E*)-2-butenyl disulfide (**XIV**) and butyl 3-methylbutanyl disulfide (**XV**). These two disulfides were not seen in later studies and may have been artifacts of the analysis. Aldrich’s identification of 2-methylquinoline was corroborated by comparison with an authentic sample, and a new compound, *S*-3-methylbutanyl thioacetate (**XVI**), was identified by comparison to a spectrum in the NBS mass spectral library.

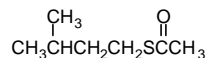


XIII



XIV

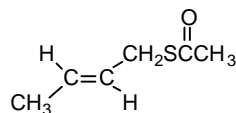
XV



XVI

In 1990, William Wood was the next player in skunk spray research [9]. In his study, GC-MS analysis was done on native

secretion and in several cases was done just minutes after collection from skunks. The two major compounds of this study were the two major thiols (**X** and **XI**) previously identified by Andersen and co-workers. Since the third major compound (**XII** and **XIII**) in each of the two Andersen studies was different, both (*E*)-2-butenyl methyl disulfide and (*E*)-2-butenyl propyl sulfide were prepared. Surprisingly, GC-MS analysis showed neither of these synthetic compounds to be in skunk spray. The third major compound of this 1990 study had the same molecular weight (molecular ion) as (*E*)-2-butenyl propyl sulfide, the compound identified in Andersen's second study, but it had a different mass spectral fragmentation pattern. A possible candidate compound with the same molecular weight, *S*-(*E*)-2-butenyl thioacetate (**XVII**), was prepared. This thioacetate had identical properties by GC-MS analysis as the compound in skunk spray. Furthermore, the ¹H-NMR spectra of *S*-(*E*)-2-butenyl thioacetate and (*E*)-2-butenyl methyl disulfide (Andersen's first study) are almost identical. It is thus likely that both the (*E*)-2-butenyl methyl disulfide and (*E*)-2-butenyl propyl sulfide reported by Andersen and co-workers as the third major component in each of their reports were actually *S*-(*E*)-2-butenyl thioacetate, **XVII**.

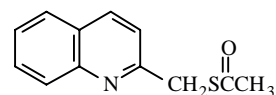
**XVII**

The incorrect assignments of these structures are easy to explain. Identical NMR spectra are usually all that is needed to assign the structure of a new simple compound. Andersen and Bernstein had no reason to perform further tests in their first study. In their second study, (*E*)-2-butenyl propyl sulfide was identified by analysis of its MS fragmentation pattern. The fragmentation patterns of this compound and *S*-(*E*)-2-butenyl thioacetate have so many similar fragments that identification without comparison to an authentic sample led to a wrong structural assignment.

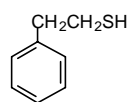
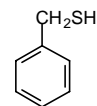
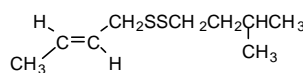
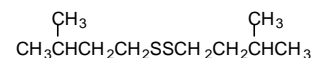
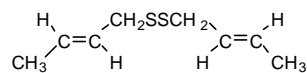
In this 1990 report, the presence of a number of compounds identified in previous studies could not be confirmed, including the two disulfides (**XIV** and **XV**) that coeluted in Andersen's second study [8], butyl (*E*)-2-butenyl disulfide and butyl 3-methylbutanyl disulfide. Perhaps these two disulfides were artifacts produced during the hour-long capillary GC-MS analysis. Andersen and co-workers did suggest that some of the compounds observed in their study might "arise from thermally induced process[es]." Because, the bis[*E*]-2-butenyl] sulfide that Stevens found in his study [7] was not detected, it too may be an artifact produced by the lengthy isolation procedure.

New natural products identified in this 1990 report were *S*-(*E*)-2-butenyl thioacetate, 2-quinolinemethanethiol, and *S*-2-quinolinemethyl thioacetate (**XVIII**). The 2-methylquinoline identified by Aldrich and Jones in 1897 [5] and the *S*-3-methylbutanyl thioacetate identified by Andersen and co-workers in 1982 [8] were reconfirmed. To summarize, this later research showed the striped skunk spray to have 7 volatile components in greater than 1% abundance. Three are thiols (**VI**, **X**, and **XI**), three are thioacetate derivatives of these

thiols (**XVI**, **XVII** and **XVIII**), and the final compound is an alkaloid, 2-methylquinoline, (**V**).

**XVIII**

Many dog owners have anecdotal tales of their pets having a faint "skunky" odor recur on damp evenings long after the odor from an encounter with a skunk had vanished. The thioacetate derivatives of (*E*)-2-buten-1-thiol and 3-methyl-1-butanethiol may be responsible for this observation. These compounds are not as volatile or odoriferous as the thiols, but are easily converted to the more potent thiols on water hydrolysis. Thus, damp conditions may lead to conversion of thioacetates trapped in animal hair to the mephitic thiols.

**XIX****XX****XXII****XXIII****XXI**

Chemicals from the Spotted Skunk (*Spilogale gracilis*)

In 1991, after finishing the work on the striped skunk, Wood examined the secretion from the spotted skunk. Unfortunately, after publication of this study, *Spilogale putorius* was divided into two species, *S. putorius* in the eastern part of the United States and *S. gracilis* in the western part. Thus, because the skunks were collected in California, the species of skunk investigated was *S. gracilis* even though the publication purports to describe *S. putorius*. The defensive secretion of the spotted skunk differs from that of the striped skunk in that it contains only thiols; it contains none of the thioacetates found in striped skunk secretion [15]. The two major thiols of the striped skunk, (*E*)-2-buten-1-thiol and 3-methyl-1-butanethiol are also the major components in the secretion of the spotted skunk. A third thiol, 2-phenylethanethiol (**XIX**), was present at moderate concentration in this smaller skunk. A number of minor compounds were identified from this species. These include phenylmethanethiol (**XX**) that Andersen et al. had found in the striped skunk [8]. Also present were the disulfides, bis[*E*]-2-butenyl] disulfide (**XXI**), (*E*)-2-butenyl 3-methylbutyl disulfide (**XXII**), and bis(3-methylbutyl) disulfide (**XXIII**), compounds that would be expected to form by air oxidation of the major thiols of this secretion.

Table 1. Composition of the Major Volatile Components (>1%) in Anal Sac Secretion from Three Species of North American Skunks (ND = None Detected)

Compound	Striped Skunk ^a	Spotted Skunk ^b	Hog nosed Skunk ^c
(<i>E</i>)-2-butene-1-thiol (X)	38–40%	30–36%	71%
3-methyl-1-butanethiol (XI)	18–26%	48–66%	ND
<i>S</i> -(<i>E</i>)-2-butenyl thioacetate (XVII)	12–18%	ND	17%
<i>S</i> -3-methylbutanyl thioacetate (XVI)	2–3%	ND	ND
2-phenylethanethiol (XIX)	trace	2–5%	ND
2-methylquinoline (V)	4–11%	trace	2%
2-quinolinemethanethiol (VI)	4–12%	trace	0.5%
<i>S</i> -2-quinolinemethyl thioacetate (XVIII)	1–4%	ND	ND

^aRange of data from 4 striped skunks. ^bRange of data from 2 spotted skunks. ^cDetermined from a single hog-nosed skunk.

Chemicals from the Hog-nosed Skunk (*Conepatus mesoleucus*)

In 1937, Fester and Bertuzzi investigated an Argentinean species of the hog-nosed skunk (*Conepatus suffocans*) [16]. These researchers had only 4 mL of secretion and were able to isolate 0.42 g of a yellow liquid with a mercaptan-like odor. From this small quantity they were not able to make a positive identification of any compounds, but did state it was very similar, but not identical, to 1-butanethiol. They speculated that the secretion contained (*E*)-2-butene-1-thiol and that, after exposure to air, their sample was mostly the oxidized form of this thiol, bis[(*E*)-2-butenyl] disulfide. However, their experimental elemental analyses for this disulfide are unacceptable when compared to the calculated values, a 2.33% difference for C, a 0.44% difference for H, and a 1.99% difference for S.

GC-MS analysis of the secretion from a North American hog-nosed skunk shows a different composition from the secretions of the spotted skunk and the striped skunk [17]. Like the secretion from the striped skunk, it does contain thioacetate derivatives of the thiols in the secretion. However, a major component of the striped and spotted skunks' secretion, 3-methyl-1-butanethiol, is missing. The major components from this skunk's secretion are (*E*)-2-butene-1-thiol and *S*-(*E*)-2-butenyl thioacetate. The minor compounds from this species are phenylmethanethiol, 2-methylquinoline, 2-quinolinemethanethiol, and bis[(*E*)-2-butenyl] disulfide.

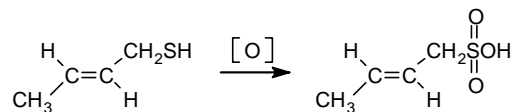
Since the hog-nosed skunk's secretion contains a thioacetate derivative of the major thiol and does not contain any 2-phenylethanethiol, it is more like the secretion of the striped than of the spotted skunk. This may indicate that the hog-nosed skunk and striped skunk are more closely related to each other than either is to the spotted skunk. A comparison of the major volatile components from these three species of skunks is presented in Table 1.

Recent taxonomic research indicates that the two species of hog-nosed skunks, *Conepatus leuconotus* and *C. mesoleucus*, reported to occur on the southern border of the United States are likely the same species. Thus, according to the rules of zoological nomenclature, the one that was described first has priority. If they are shown to be the same species, the name *C. leuconotus* will be used [18].

Deodorizing Skunk Spray

There are many different recipes for the removal of skunk spray from pets and other sprayed objects. The most common is the use of tomato juice. Bathing an animal in tomato juice

seems to work because at high doses of skunk spray the human nose quits smelling the odor (olfactory fatigue). When this happens, the odor of tomato juice can easily be detected. A person suffering olfactory fatigue to skunk spray will swear that the skunk odor is gone, apparently neutralized by the tomato juice. Another person coming on the scene at this point will readily confirm that the skunk spray has not been neutralized by the tomato juice (personal observation by WFW). To get rid of the odor of skunk spray, it is necessary to change the thiols into compounds that have little or no odor. Oxidizing the thiols to sulfonic acids can easily do this.



Many oxidizing agents can effect this change. For pets, Paul Krebaum of Lisle, Illinois developed one of the best home remedies, an adaptation of a laboratory method he used to destroy hydrogen sulfide and thiols [19].

- Bathe the animal in a mixture of 1 quart of 3% hydrogen peroxide (from drug store), 1/4 cup of baking soda (sodium bicarbonate), and a teaspoon of liquid detergent.
- After 5 minutes rinse the animal with water.
- Repeat if necessary.
- The mixture must be used after mixing and will not work if it is stored for any length of time. Since it releases oxygen, it cannot be stored in a closed container. For inanimate objects one cup of sodium hypochlorite solutions (liquid laundry bleach) in a gallon of water is cheap and effective.

Glossary of Names and Terms

The nomenclature of chemicals in this review uses the current rules codified by the International Union of Pure and Applied Chemistry (IUPAC). Much of the older literature uses different nomenclature systems reflecting usage at that time. A major shift in chemical names has been to replace the term *mercaptan* by *thiol* for the R-SH functional group. Designations of the spatial orientation of groups attached to a double bond has also changed. The terms *cis* and *trans* have been replaced with the prefixes (*Z*) and (*E*) to indicate the orientation of substituents on a double bond. These prefixes use different nomenclature rules to describe the orientation of substituents, so there is no way to directly translate the use of these prefixes from one system to another. In many cases,

however, the use of the prefix *trans* will coincide with the prefix (*E*). Finally, the prefixes *S*- and (*S*)- are different and should not be confused. *S*- is used to indicate a point of attachment to sulfur (e.g., *S*-3-methylbutanyl thioacetate), while (*S*)- denotes the spatial orientation of substituents on a stereogenic center.

IUPAC Names Compared to Common Names Used in Previous Reports

- a) bis(*E*)-2-butenyl] disulfide = dicrotyl disulfide
- b) bis(*E*)-2-butenyl] sulfide = dicrotyl sulfide
- c) 1-butanethiol = butyl mercaptan, normal-butyl mercaptan, *n*-butyl mercaptan
- d) (*E*)-2-butene-1-thiol = *trans*-2-butene-1-thiol, crotyl mercaptan
- e) (*E*)-2-butenyl methyl disulfide = *trans*-2-butenyl methyl disulfide
- f) (*E*)-2-butenyl propyl sulfide = *trans*-2-butenyl propyl sulfide
- g) butyl (*E*)-2-butenyl disulfide = *n*-butyl crotyl disulfide
- h) butyl 3-methylbutanyl disulfide = *n*-butyl isoamyl disulfide
- i) 3-methyl-1-butanethiol = iso-amyl mercaptan, isoamyl mercaptan
- j) 2-methylquinoline = α -methyl-quinoline

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