

土壤挥发性汞释放通量的研究*

冯新斌 陈业材 朱卫国

(中国科学院地球化学研究所环境地球化学国家重点实验室, 贵阳 550002)

摘要 在总结前人工作的基础上, 建立了一套野外现场测量土壤挥发性汞释放通量的实验装置, 于1993-08至1993-10在贵州省三类地区(高汞区、人为汞污染区和背景参考区)的5个采样点进行土壤挥发性汞释放通量的研究。结果表明, 土壤挥发性汞释放通量具有白天高于夜间的昼夜变化规律; 土壤挥发性汞释放通量与土壤总汞含量、大气气温相关。

关键词 汞, 释放通量, 通量箱, 贵州省, 丹寨汞矿。

国外很多学者^[1-5]对水体表面挥发性汞释放通量做了很详细的研究工作。少数学者^[4,5]对土壤挥发性汞释放通量也做了一些研究工作, 由于在采样设备方面存在问题, 所以没有得出有意义的结果。目前对土壤挥发性汞的释放通量的时空变化规律以及影响土壤挥发性汞释放通量的因素仍不清楚。

笔者运用通量箱技术对土壤挥发性汞释放通量进行研究。该技术可以获得在动态环境状况下土壤挥发性汞的释放通量值, 能比较客观地反映土壤挥发性汞释放过程的时空变化规律。目前, 该法是在野外获得水体和土壤表面挥发性汞释放通量的唯一可行的方法^[5]。

1 实验方法

1.1 大气汞的采样方法

本研究采用金丝捕汞管捕集大气中的汞, 捕集(采样)效率>95%。

大气汞的样品采集装置见图1, 其中装置中干燥管的作用是吸收大气中的水蒸气, 以免水蒸气吸附于捕汞管壁或金丝表面而影响捕汞管的采样效率和分析精度。串联2支捕汞管是为了保证大气中的汞完全被采集到。采样流量为1 L/min。采样时间长短可根据大气汞的浓度高低而定, 以保证捕汞管收集的汞量处于分析仪器的最佳灵敏度范围内。

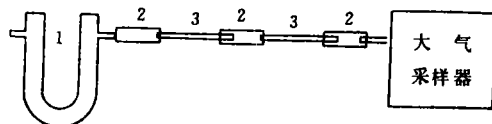


图1 大气汞的采样装置图

1 装有无水氯化钙的U型干燥管

2 橡胶联结管 3 金丝捕汞管

干燥剂的选择应遵循的原则是: 吸水性强, 不吸附汞。本研究采用无水二氯化钙作干燥剂。

1.2 通量箱法测定土壤挥发性汞释放通量的计算

Xiao等^[5]和Schroeder等^[4]利用采集水体表面挥发性汞释放通量的不锈钢通量箱对土壤挥发性汞的释放通量做了一些研究工作, 但结果不理想。一方面是由于金属对汞有吸附性, 另一方面是由于不锈钢通量箱是不透明的。当不透明的通量箱置于土壤上方必然会造成被研究的土壤所处的环境条件与真实情况不一致, 由于阳光不能照射到所研究的土壤上面, 土壤温度以及土壤上方大气的温度也会降低等等, 从而造成汞释放通量值偏离真实值。鉴于以上不足, 本研究选用有机玻璃制作通量箱, 箱外形为80 cm×20 cm×20 cm的长方体(见图2), 箱

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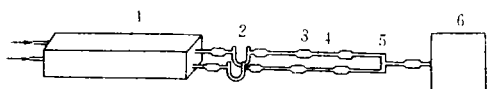


图2 土壤挥发汞释放通量野外采样装置示意图

1 通量箱 2 装有无水氯化钙的 U 型干燥管
3 橡胶联结管 4 金丝捕汞管 5 三通管 6 大气采样器

大气经 2 个进气口被大气采样器抽入采样箱中,从采样箱出来的大气中的汞被联结在通量箱出气端的 4 个金丝捕汞管捕获,采样流量为 1 L/min,采样时间长短的选择依据同 1.1 所述。

野外采集土壤挥发性汞释放通量样时,首先将通量箱底板卸掉,然后把通量箱置于土壤表面,见图 3。

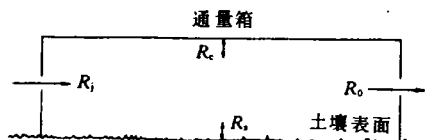


图3 计算土壤挥发性汞释放通量的原理示意图

单位时间内由采样箱出气端捕汞管采集的汞量 R 。可以由以下公式表示出:

$$R_o = R_i + R_v + R_g \quad (1)$$

其中, R_i 为单位时间内进入箱内的大气中汞的量; R_v 为单位时间内由通量箱内壁释放的汞量,即为通量箱的空白值; R_g 为单位时间内由土壤释放的汞量。

R_i 值可以用图 1 所述的装置在测通量样时同时测出。

R_v 值,即通量箱的空白值,可以利用图 2 所示的装置,其中将通量箱的底板装上,用测量通量样的方法测出,这样:

$$R_v = R'_o - R'_i \quad (2)$$

通量箱的空白值在每次测量土壤通量之前和之后各测 1 次,然后取平均值。

这样,单位时间内由土壤释放的汞量 R_g 则由下式计算出:

$$R_g = (R_o - R_i) - R_v \quad (3)$$

R_g 可以是正值,也可以是负值。正值表明汞从

土壤向大气释放;负值则表明大气汞向土壤沉降。

为了研究土壤挥发性汞释放通量的昼夜变化规律,分别在上述 5 个采样点进行白天和夜间采样,在采通量样的同时测量大气温度和大气相对湿度。

1.3 汞的分析方法

汞的分析方法采用 2 次汞齐法^[6],即首先将环境介质中的汞收集于采样用的捕汞管中,其次将已采好样的捕汞管置于加热炉中在 700℃ 高温下将汞释放出,并捕集到一支专门供分析用的捕汞管上,最后,在同样的温度下热解分析用的捕汞管,将释放出的汞蒸气抽入 GC-5 型微机测汞仪中进行分析。该方法的最低检出限为 0.05 ng。

采用 2 次汞齐法分析样品中的汞,一方面排除了干扰物质对分析的影响;另一方面可以消除捕汞管之间因金丝缠绕形状差异等物理因素而造成的分析误差。

2 采样点的选择及采样点土壤汞的存在形式

2.1 采样点的选择

在贵州省境内,选择了 3 类地区,即高汞区、人为汞污染区和背景参考区。将丹寨汞矿区作为高汞区,并根据土壤中汞含量由高到低选择了 3 个采样点,分别是丹寨汞矿复兴厂、丹寨汞矿一车间和丹寨汞矿厂部(根据贵州省 104 地质大队提供的 1:5 万丹寨、普安幅的土壤汞地球化学异常图);选择清镇东门桥汞污染农田作为人为汞污染区;选择贵州省农科院试验田作为背景参考区。在清镇和贵州省农科院分别选择了 1 个采样点。5 个采样点土壤类型均为石灰土。

2.2 采样点土壤中汞的存在形式

采用连续化学浸取法,对土壤汞的存在形式及含量作了分析,其结果见表 1。

3 结果与讨论

表 2 列出了 5 个采样点土壤挥发性汞释放通量的测定结果。

表 1 土壤汞形态分析结果(μg/g)

采样地点	土 壤 汞 的 形 态							各态汞 总含量	王水消 化总汞
	水溶态	交换态	碳酸盐 等结合态	腐殖酸 结合态	易氧化 有机质 结合态	难氧化 有机质 结合态	残渣态		
清镇	未检出	0.023	0.021	0.115	0.150	1.288	0.321	1.918	1.970
贵州省农科院	0.020	0.012	0.038	0.023	0.034	0.018	0.213	0.358	0.345
丹寨汞矿厂部	0.019	0.065	0.031	0.046	0.029	未检出	0.741	0.931	0.871
丹寨汞矿复兴厂	0.036	0.073	0.038	0.220	0.081	0.031	19.246	19.725	19.984
丹寨汞矿一车间	0.009	0.066	0.073	0.116	0.087	0.004	9.940	10.295	10.896

表 2 土壤挥发性汞释放通量测定结果

采样日期 (月-日)	采样时间	采样地点	挥发性汞释放通量 [ng/(m ² ·h)]	大气温度 (℃)	大气相对 湿度(%)	大气汞平均 浓度(ng/m ³)	通量样 采样数
10-09	12:41-14:21	丹寨汞矿复兴厂	145.38±45.54	27.3	48.5	71.43±12.19	4
10-09	20:26-22:43		30.06±8.34	17.0	69.3	16.08±2.27	4
10-14	11:04-12:29		22.66±7.00	16.4	60.0	27.11±4.19	4
10-10	11:45-15:40	丹寨汞矿厂部	29.76	29.5	45.0	77.77±46.93	1
10-11	16:12-17:42		12.51±4.70	26.7	57.5	43.79±30.34	4
10-12	22:03-23:30		-18.80±3.79	15.9	92.0	57.07±12.34	4
10-13	10:33-12:01	丹寨汞矿一车间	92.18±10.61	26.2	41.0	249.18±9.28	2
10-13	16:36-17:42		82.55±28.66	23.8	50.8	71.27±9.28	4
10-13	21:54-23:20		10.05±0.32	21.2	54.0	38.01±12.56	4
11-01	13:14-16:24	省农科院实验田	16.64±1.21	21.9	30.0	25.07	2
11-01	21:17-23:05		-2.26±0.57	9.0	92.5	10.56	2
11-14	13:00-14:30	清镇东门桥	26.63±6.63	23.4	27.5	82.28±40.41	2
11-14	19:17-20:47		2.40	14.7	43.5	33.10±28.98	1

从图 4 中可以看出, 5 个采样点土壤挥发性汞释放通量表现出一致性的昼夜变化规律: 即

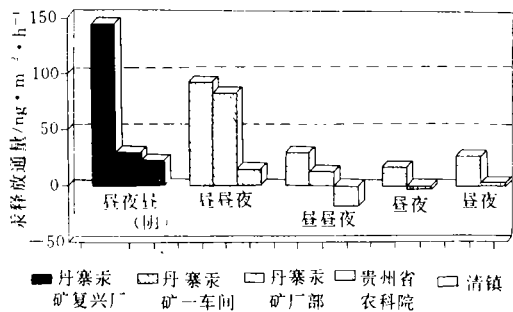


图 4 5 个不同采样点土壤挥发性汞释放通量的昼夜变化规律

白天土壤挥发性汞释放通量高于夜间。从表 2 可以看出: 5 个采样点都有一个共同的规律, 即土壤挥发性汞释放通量大小与大气气温有关。大气气温愈高, 土壤挥发性汞释放通量也愈大。特别是在丹寨汞矿复兴厂由于 10-14 为阴天, 大气气温比 10-09 夜间低, 结果 10-14 白天测定的土壤挥发性汞释放通量略低于 10-09 夜间测

定值。显然土壤挥发性汞释放通量的昼夜变化规律是由大气气温变化造成的, 这表明土壤挥发性汞释放通量受大气气温的制约。

从图 4 中可以看出: 在相同大气气温条件下, 土壤挥发性汞释放通量由大到小的排列顺序为: 丹寨汞矿复兴厂、丹寨汞矿一车间、清镇汞污染农田、丹寨汞矿厂部和贵州省农科院。这与土壤中总汞含量由高到低的排列顺序一致。这表明土壤挥发汞的释放通量大小明显地与土壤中汞的含量高低有关, 在大气气温接近的情况下, 土壤中汞的含量越高, 土壤挥发性汞的释放通量也越大。

从图 4 中还发现丹寨汞矿厂部和贵州省农科院试验田夜间土壤挥发性汞的释放通量为负值, 表明大气汞向土壤表面沉降。在夜间采样时, 这 2 个测点大气相对湿度很高(见表 2), 丹寨汞矿厂部为 92%, 农科院试验田为 92.5%。这表明, 当大气相对湿度较大时, 会造成大气中汞向土壤沉降。

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只在 10000 h^{-1} 时有较大增加。经色谱(PID)测定,尾气中除 CO_2 、 CO 、 CH_4 还出现了 4 个不同的色谱峰。David^[5]的工作报道了 Ru 催化剂对 CO 加氢反应时有多碳化物生成,这与笔者的测定是吻合的。

2.4 进气 $\text{CO}_2 : \text{H}_2$ 值对 CO_2 的影响

CO_2 加氢反应:



1 mol 的 CO_2 完全反应需 4 mol 的 H_2 。图 4 给出

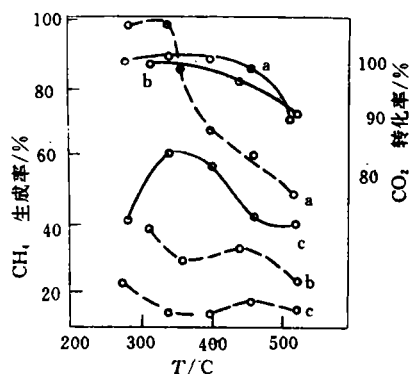


图 4 不同的 $\text{CO}_2 : \text{H}_2$ 值对 CO_2 转化率及 CH_4 生成率的影响

a. $\text{CO}_2 : \text{H}_2 = 1 : 5$ b. $\text{CO}_2 : \text{H}_2 = 1 : 4$
c. $\text{CO}_2 : \text{H}_2 = 1 : 1.8$

实线为 CO_2 转化率,虚线为 CH_4 生产率

了 $\text{CO}_2 : \text{H}_2 = 1 : 5, 1 : 4, 1 : 1.8$ 时 CO_2 的转化率和 CH_4 的生成率。从图 4 可以看出,随 $\text{CO}_2 : \text{H}_2$ 值降低, CO_2 转化率、 CH_4 生成率均降低。尤其缺 H_2 条件下更为明显。富 H_2 条件下反应温度在 $280-340^\circ\text{C}$ 范围内, CH_4 的生成率与 CO_2 转化率相近。此时可获得 CO_2 催化加氢转化为 CH_4 的最佳产率。

3 结论

(1) 采用 $\text{Ru}/\text{Al}_2\text{O}_3$ 催化剂对 CO_2 进行加氢转化,可以有效地将其转化为 CH_4 和 CO 。

(2) 从 CH_4 的生成率考虑,反应温度选择 $450-470^\circ\text{C}$,空速选择 10000 h^{-1} 可获得满意的产率。

(3) CO_2 催化加氢反应为放热反应,在高空速下不但催化剂的起动温度低,而且反应过程中能源消耗少,并能获得较高 CH_4 产量。因此选择较高空速(试验值为 10000 h^{-1})为好。

致谢 胡克源研究员对改进 $\text{Ru}/\text{Al}_2\text{O}_3$ 催化剂的性能提供了指导性建议,特此表示谢意。

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将土壤各相态汞含量以及土壤中总汞含量,大气气温值,对土壤挥发性汞释放通量的对数进行多元逐步回归分析,得出回归方程如下:

$$\ln y = 52.096 + 0.500 \ln C - 14632.356/T \quad (4)$$

复相关系数: $R=0.8792$

式中, C : 土壤中汞的总含量; y : 通量回归值; T : 大气绝对温度(单位为 K)。

从回归方程可以看出,土壤挥发性汞释放通量只与土壤总汞含量相关,而与土壤中单一相态的汞不相关。

致谢 在本文写作中得到谢鸿森教授、洪业汤教授和余志成教授的指导,谨致谢意。

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A Research on the Ecological Effect of the Soil Animals Community by the Heavy Metal Pollution. Deng Jifu et al. (Zhuzhou Institute of Environ. Sci., Zhuzhou 412000); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 1-5

The research results show that there are 31 soil animal species in the polluted area, in which *Acarina* and *Collembola* are dominant population. The species and quantities of the soil animals are decreased with the aggravation of pollution, which can be found mainly from the growth and decline of the dominant population and decrease and disappearance of the polluted sensitive species. The big animals, such as earthworm and spider, have a strong ability to accumulate heavy metal elements. The content of Cd, Pb, As in these animal's body relates proportionally to the metals in soil, but the centipede's ability in accumulating the heavy metal elements is obviously weaken.

Key words: heavy metal pollution, soil animal, ecological distribution, accumulation.

Microbial Degradation of Regenerated Cellulose Film. Zheng Lianshuang et al. (Dept. of Environ. Sci. Wuhan University, Wuhan 430072); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 6-8

The biodegradability of regenerated cellulose film was tested by soil-burial test in field, culture-dish test and CO₂ evolution test respectively. The results of test are as follows: (1) The mass loss of the film increased with the extension of soil-burial test; (2) Test strains had different abilities to degrade the film, and the order of their abilities was strain T-311 > strain A-305 > strain P-307; the biodegradation rate of the film might exceed 70% during 42 days after the film had been buried or inoculated with strain T-311; (4) In the process of biodegradation, mass loss, visible growth of test strains on the film and CO₂ evolution are both relative and different indexes for assessing biodegradation degrees of the film.

Key words: regenerated cellulose film, biodegradability, CO₂ evolution.

Adsorption Behavior of Ammonium Ion in Saturated Silty Sand and Sandy Loam. Zhu Wapeng et al. (Dept. of Environ. Eng., Tsinghua University, Beijing 100084); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 9-11

The adsorption characteristics of ammonium ion in saturated silty sand and sandy loam were studied by means of dynamic soil column experiments. The transportation of ammonium ion in soil were modelled with a combined equilibrium and kinetic adsorption model (Cameron's model). The coefficients (K_1 , K_2 and K_3) under different soil and NH₄⁺ concentration in water were obtained. The distribution curves of ammonium ion in soil were drawn. The results indicate that the longitudinal dispersion coefficients (D) in silty sand and sandy loam are 0.175 cm²/min and 0.0093 cm²/min respectively. The dynamic adsorption capacity of silty sand are 0.156 mg/g when concentration of NH₄⁺ in water is 13.7 mg/L and

0.400 mg/g when concentration of NH₄⁺ in water is 41.0 mg/L; the dynamic adsorption capacity of sandy loam is 1.33 mg/g when concentration of NH₄⁺ in water is 51.0 mg/L. Above results can be used to determine the suitable thickness of protective soil in land treatment system of wastewater.

Key words: ammonium ion, saturated silty sand, saturated sandy loam, transportation, dynamic soil column experiment.

Study on the Adsorption Mechanism of Mercury (I) with Prime Amine N₁₉₂₃ Levextrel Resin. Cheng Deping and Xia Shijun (Dept. of Chem., Hangzhou University, Hangzhou 310028); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 12-15

The adsorption mechanisms of mercury (I) with prime amine (N₁₉₂₃) levextrel resin were studied when it doesn't form salt or it is in salt forming condition. The adsorption compounds have been determined and the different mechanisms have been analysed from the results obtained by using constant mole method, slope method, saturated capacity method, IR and NMR spectra, and also discussed the different mechanism in low or high concentration of [HCl] on the theory.

Key words: mercury, mechanism, levextrel resin, primary amine N₁₉₂₃.

A Study on Effects of Simulated Acid Rain and Sulphur Dioxide on Crops. Liu Liangui et al. (Chinese Research Academy of Environmental Sciences, Beijing 100012); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 16-19

The effects of acid rain and sulphur dioxide alone and in combination on tomato, carrot and cotton was studied by simulated acid rain irrigating and SO₂ exposure. It was found that the simulated acid rain and sulfur dioxide could inhibit the growth of crops in a degree and reduce the productivity. The synthetic effect of acid rain and sulfur dioxide was more notable than alone, but their mutual effect was not marked.

Key words: simulated acid rain, sulfur dioxide, crop, inhibition, synthetic effect.

The Fluxes of Volatile Mercury over Soil Surface in Guizhou Province. Feng Xinbin et al. (State key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, 550002); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 20-22

After summing up the work of former researchers, the authors set up a instrument which can be used to measure the fluxes of volatile mercury over soil in field. From Aug. to Oct. in 1993, the authors studied the fluxes of volatile mercury over soil at five sites of three different areas (high mercury contented area, mercury polluted area and reference area). Studies showed that soil release more volatile mercury in day than at night, and that the fluxes of volatile mercury over soil has relationship with both the total mercury content of soil and air temperature.

Key words: mercury, fluxes, flux chamber, Guizhou

Province, Danzai Mercury Deposit.

Study on the Catalytically Hydrogenated Conversion of CO₂ Using Ru/Al₂O₃ Catalyst. Zhao Ruilan et al. (Research Center for Eco-Environmental Sciences, Academy of Sciences, Beijing 100085); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 23–25

In this paper the catalytically hydrogenated conversion of CO₂ was studied using Ru/Al₂O₃ catalyst, the influence of different reaction conditions, such as reaction temperature (260–520 °C, 5000–10000 h⁻¹) and CO₂/H₂ ratio in inlet gas, on CO₂ conversion efficiency and CH₄ formation were reported. At reaction temperature higher than 350 °C the CO₂ conversion efficiency was over 95%, and CH₄ formation rate was about 45%–79%. There was no significant influence on CO₂ conversion efficiency and H₂O formation when the space velocity from 5000 h⁻¹ to 10000 h⁻¹. However, for the CH₄ formation efficiency there was a trough at the space velocity of 7000–9000 h⁻¹. The CO formation changed a little at space velocity of 5000–9000 h⁻¹, but it increased a lot at 10000 h⁻¹. The higher CH₄ formation efficiency was obtained when there existed excess of H₂. The highest CH₄ formation efficiency obtained was 98%.

Key words: carbon dioxide, catalyst, catalytically hydrogenated, methane.

Monitoring on The Concentration of Atmospheric Methane of A Rice Cropping Region in Beijing Area. Cui Ping et al. (Chinese Research Academy of Environmental Sciences, Beijing 100012); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 26–28

Monitoring on methane concentration in the atmosphere in the rice cropping region was carried out between Oct. 1991 and Nov. 1993. Results indicated that the average concentration of methane of the two testing years in the local region were 1.16 and 1.17 µg/L respectively. The variation of methane concentrations showed a strong seasonal pattern. The concentration and concentration deviation were high in summer and low in winter. During rice vegetation period, the methane concentrations were closely related with the variation of methane emission rates from rice paddies indicating rice paddies is one of the most important methane sources of the region. Running analysis showed that the average increasing rate of atmospheric methane in the region was 0.2%, much lower than some previous reports.

Key words: methane, rice, monitoring, Beijing area.

A simulation Study on the Accumulation of Added Rare Earth Elements in Aquatic Ecosystem. Chen Zhaoxi et al. (Dept. of Chem. Eng., East China Institute of Metallurgy, Maanshan 243002); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 29–31

The accumulation and distribution coefficients of added rare earth elements (RE) in various parts of simulated aquatic ecosystem were investigated. The results showed that concentrations of added RE in bottom mud and water bodies varied smoothly and in *Lemna minor* and *Cyprinus carpio* varied extremely with the time in the period of experiment. Distribution coefficients of added RE in bottom mud were higher than 96%, in *Lemna minor*, were range of 0.26–1.61%, in water, were range of 0.54%

–0.91%; and in carp were less than 0.035%, but almost on linear increment in the period of experiment. Bio-concentration of added RE in carp was also discussed.

Key words: aquatic ecosystem, accumulation, rare earth elements, bioconcentration.

The Quantum Chemistry Studies of the biradical Mechanism of Destroying Ozone in the Atmosphere. Sun Huabin et al. (Institute of Military Medicine, Jinan Command, Jinan 250014); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 32–34

The reaction mechanisms of the singlet biradicals NH, CH₂, CCl₂ with ozone in the atmosphere have been studied using RHF method of quantum chemistry. The geometries of the reactants, intermediates and products of the above reactions are optimized with the gradient technique at the 3-21G level, their energies have been calculated at the 6-31G or 6-21G level. The structure data of all species have been obtained. The calculated results show that there are two stages in the above reactions, the reactions of the biradicals with ozone take place first to form the stable intermediates, then the intermediates are decomposed by illuminating to the stable molecules HNO, H₂CO and Cl₂CO etc., respectively. In terms of dynamics two reactions in two stages belong to the types [$\pi_{4s} + W_{2s}$] and [$\pi_{2s} + \pi_{2s}$], respectively, and they are permitted thermodynamically. In this study, a method to investigate complicated reaction based on the combining thermodynamics with Woodward-Hoffmann approach without calculation of transition state was attempted to provide by authors.

Key words: biradical, loss of ozone, reaction mechanism.

The Structure and Toxicity Relationship Study for Nitroaromatics to *Scenedesmus obliquus*. Lu Guanghua et al. (Dept. of Environ. Sci., Northeast Normal Univ., Changchun 130024); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 35–36

ELUMO, EHOMO, $\Delta(\Delta H_f)$, μ and Q_{NO_2} of 18 nitroaromatic compounds were calculated using the quantum chemical method MNDO. The quantitative structure-activity relationships (QSAR) were developed using the five quantum chemical descriptors for the acute toxicity of nitroaromatics to *Scenedesmus obliquus*. Through step-wise regression analysis, one best equation contained three variables was obtained: $-\log EC_{50} = 2.92 - 0.077\Delta(\Delta H_f) + 0.08\mu + 0.28E_{HOMO}$, $n = 18$, $r = 0.961$, $S = 0.173$. The equation was used to estimate the toxicity of the studied compounds, and the toxic effect was discussed.

Key words: structure, toxicity, nitroaromatics, *Scenedesmus obliquus*.

Effects of Rare-Earth Elements on Growth and Reproduction of *Chlorella pyrenoides*. Hu Qin Hai et al. (Dept. of Environ. Sci., Zhejiang Agricultural University, Hangzhou 310029); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 37–38

It was studied that effects of rare-earth elements (La, Ce, Pr, Nd and their mixture) on growth and reproduction of *Chlorella pyrenoides*. The results showed that effects of rare-earth elements on growth and reproduction of *Chlorella pyrenoides* were not apparent under lower concentration (2 mg/L), but it was inhibited as the concen-