HIGHER EDUCATION TECHNICAL SCHOOL
OF PROFESSIONAL STUDIES
Novi Sad

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SPECIAL MOBILITY STRAND

FIRE INVESTIGATION

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The Higher Education Technical School of Professional Studies in Novi Sad is a higher education institution that celebrates its 60th anniversary this year. We educate our students at four departments: mechanics, protection, graphics and electrical engineering. In the current third cycle of accreditation of study programs for the period 2017-2023 we have accredited 10 three-year study programs at the basic studies and 7 one-year specialist study programs. Amendments to the Law on Higher Education [1], allowed professional master studies, accordingly, and in the framework of ERASMUS + project K-FORCE, in 2018 we accredited the two-year master study program Protection Engineering. The aim was to enable this study program to provide the vertical continuation of the education to our graduated students of the basic study programs: Protection against catastrophic events and fires, Safety at work and Environmental protection, as well as other interested candidates. Within the mentioned master program, there is a course Investigation of causes, phases and consequences of a fire, and within this lecture the goal is to present in general the material that is being studied in this subject.

COMBUSTION

Materials:

- *combustible (flammable)*

1. *easily flammable (paper)*
2. *harder to ignite (wool, hair, PVC)*

- *nonflammable (quartz, glass)*

Fire triangle:

- *combustible material*
- *oxidizer*
- *heat*

Methods of ignition of substances:

- *piloted ignition*
- *nonpiloted ignition (thermal ignition, autoignition)*

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Gas combustion:

- *lean flammability limit (explosiveness)*
- *upper flammability limit (explosiveness)*
- *stoichiometric mixture*
- *explosion*
- *deflagration*
- *detonation*

Burning of liquid:

- *actually the burning of its vapor*
- *flash point of the liquid*
- *fire point of the liquid*

Division of liquids based on their flash point:

- *Class I (< 38°C)*
- *Class II (≥ 38°C < 60°C)*
- *Class III (≥ 60°C)*

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Table 8-1 Flash Points of Some Common Liquids

	Flash Point*	
	°C	°F
Class I Liquids		
gasoline	–45.5	–50
ethyl ether (anesthetic)	–28.9	–20
n-hexane	–3.9	25
JP-4 (jet aviation fuel)††	–18	0
acetone	–17.8	0
toluene	4.4	40
methanol	12.2	54
ethanol	12.8	55
turpentine†	35	95
Class II Liquids		
No. 2 fuel oil (domestic)††	>38	>100
diesel fuel†	40 to 55	104 to 131
Jet A (jet aviation fuel)††	47	117
kerosene	37.8	100
No. 5 fuel oil††	>54	>130
Class III Liquids		
JP-5 (aviation jet fuel)††	66	151
SAE No. 10 lube oil††	171	340
tricresyl phosphate††	243	469

Source: [3]

Mechanisms of solid materials combustion:

- *direct combustion - carbon and solid chemical elements (Si, Ti, B, Zr)*
- *combustion with a change in the aggregate state (wax, paraffin, grease)*
- *combustion with the decomposition (pyrolysis)*

Pyrolysis:

- *anaerobic pyrolysis (endothermic)*
- *oxidative pyrolysis (endothermic or thermally neutral)*

Phases of solid matter combustion:

- *combustion of gaseous products of decomposition (flame)*
- *solid residue combustion (no flame)*

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Two ways of burning solid substances:

- *flaming combustion*
- *nonflaming combustion (smoldering or glowing combustion)*
- *for most organic solids, the ignition temperature is 270-400°C and self-ignition temperature around 600°C*

After the solid gets inflamed, two ways of further behavior are possible:

- *charring combustibles (wood and certain plastic materials)*
- *noncharring combustibles (large number of common plastic masses such as polyethylene, polystyrene and acrylic)*

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Dusts:

- *Dusts according to the place of formation, are divided into:*

1. *natural dusts (not prone to explosion)*
2. *technical dusts (cement, plaster, flour)*

- *ignition temperature of the cloud of dust*
- *smoldering temperature of the deposited powder (dust)*

Mechanisms of heat transfer:

- *conduction*
- *flow (convection, mixing)*
- *radiation*

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FIRES

- *Fire is an uncontrolled, unwanted and destructive combustion.*
- *The cause of fire is the way of the forming of the heat which caused the fire.*
- *Causes of fire can be:*

1. *direct contact with flame or glowing material*
2. *electrical current (overheating of electrical conductors, short circuit, large transient resistance, sparking and electric arc, electric-thermal devices)*
3. *static electricity (oil, rubber, paper, textile industries)*
4. *natural causes of fire (atmospheric electricity discharge, earthquake, thermal effects of the sun)*
5. *mechanical causes of fire (friction, pressure, shock)*
6. *self-ignition (oils, coal, materials of plant origin - cereals, straw, hay)*
7. *exothermic materials (thermal instability, self-polymerization, intra and intermolecular oxidation-reduction)*

- *Center of the fire, place where the fire first appeared.*
- *The area by which the fire spread is called a fire scene.*
- *fire risks (a children's play, a faulty installation, a construction defect, etc.)*
- *external fire manifestations:*

1. *color and flame size*
2. *quantity, density and color of the smoke*
3. *smells before fire, during fire and during the investigation*
4. *quantity and appearance of particles of the char (soot)*
5. *sounds (breaking, cracking, explosion)*

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Figure 10-1 The two basic kinds of smoke emanating from a fire.

Source: [3]

According to the area in which they occur:

- *outdoor fires (forest fire, fires of cereal fields, fires of stubbles)*
- *indoor fires (stages of development: burning, spreading, flashover (fire jump), blasting phase, fire diminishing)*
- *fires on the means of transport:*

1. *passenger traffic (road vehicles, trains, planes, ships)*
2. *freight traffic (road vehicles, trains, planes, ships)*
3. *machinery (construction, agriculture, and machinery in other branches of industry)*

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MATERIALS BEHAVIOUR IN FIRE

Based on the appearance of certain materials after the flame and high temperature cease to make effect:

- *we can conclude what kind of processes took place during the fire*
- *detect the phases of the fire*
- *detect where from the fire was transmitted*
- *and thus reach the place where the combustion began*
- *it is necessary to take into account the conditions for air supply, draught or artificial ventilation*

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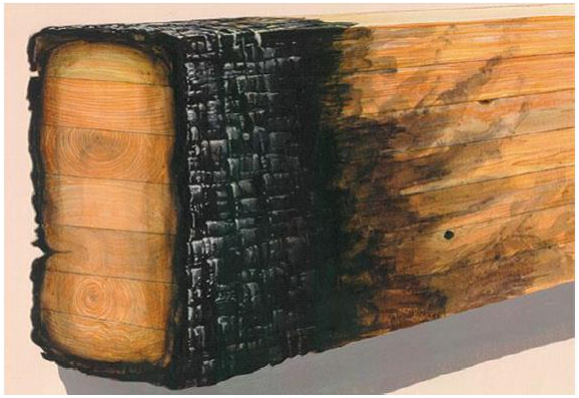
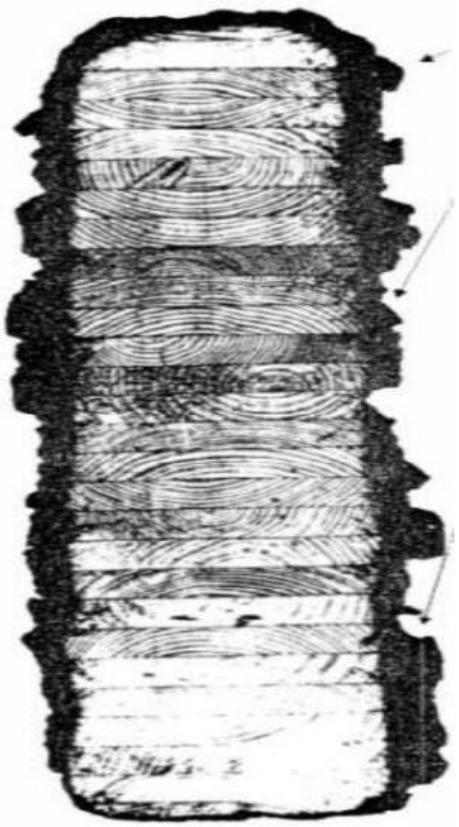
Wood

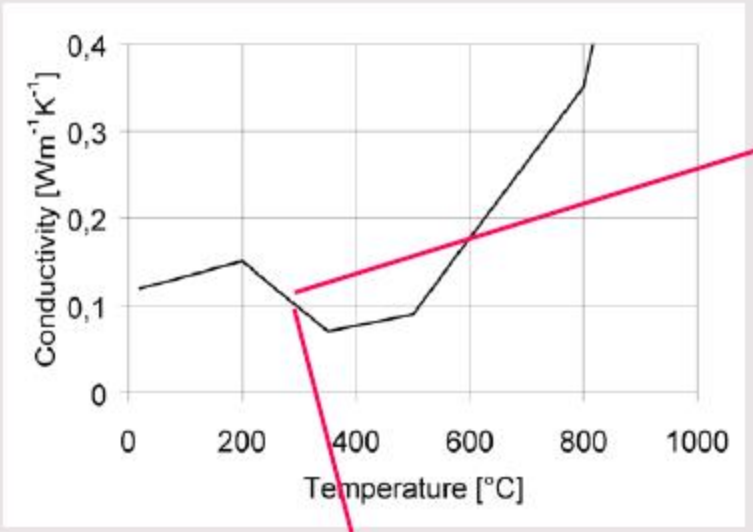
- *degree of flammability of wood (type of wood, the processing of the surface, the size of the pieces, the humidity)*
- *ignition temperature 250-300°C*
- *charred layer - "crocodile skin"*

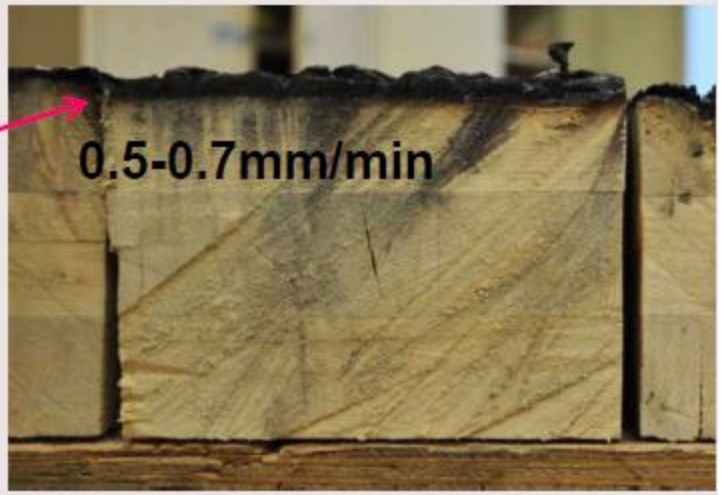




Source: [7]

THERMAL CONDUCTIVITY OF WOOD AND THE CHAR LAYER





Temperature °C	Thermal conductivity $Wm^{-1}K^{-1}$
20	0,12
200	0,15
350	0,07
500	0,09
800	0,35
1200	1,50

Source: [12]

Glass

- *ordinary glass nonflammable material*
- *in a fire glass cracks quickly due to thermal shock*
- *not considered as a fire-resistant material*
- *borosilicate and multilayer glass can be used as a fire barrier*

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Brick

- *obtained from clay which at about 900°C*
- *melting point about 1200°C and therefore there are no major damages and deformations in the fire*
- *bricks are connected and coated with mortar which protect them from fire to the some extent*

Lime mortar

- *a mixture of slaked lime, sand and water*
- *effective fire protection agent*
- *due to water releasing at about 530°C smaller or larger pieces of mortar peeling off, thus leaving the walls bare and exposed to direct fire effects, by tracing these traces, the direction of the spread of fire can be determined*

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Source: [7]

Stone

- *the oldest natural construction material*
- *natural stone used in the construction:*

1. *sedimentary rock (limestones, dolomites, sandstones)*
2. *metamorphic rock (marble)*
3. *magmatic rock (granite)*

- *granite cracks occur at 500-600°C, and at 800°C, the granite elements are ruined*
- *limestone begins to crack at about 600°C*

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Concrete

- *a mixture of cement and aggregates (sand, gravel, ...) with water*
- *above 500°C, ordinary concrete begins to peel off*
- *reinforced concrete at 400-600°C, the changes reach a critical size and constructions collapse*
- *color of the concrete indicates the temperature it was exposed*
- *load capacity of the concrete structures exposed to fire should be tested before returning them to use*

Change of color of the concrete.
Red color indicate temperaures round 600^0C

Source: [12]

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Experimental determination of the residual concrete strength

The speciment are taken without the destruction of reinforcement and tested at the Testing laboratory of the Faculty of Civil Engineering in Skopje

Before testing all the specimens are divided in two slices. Deteriorated (burned) slices had small height (3-6cm) and rough surface

Source: [12]

Change of color and structure of concrete (fissures and cracks inside the concrete mass)

concrete specimen extracted from the RC slab between the 7th and 8th floor

Change of concrete colour and fissures and cracks inside the concrete mass in slab over the 7th flour

Source: [12]

Steel

- *very unreliable from the aspect of fire protection, if it is not protected unprotected and fully loaded steel elements remain stable on fire for 15 to 30 minutes*
- *the wear of the steel structure will be depleted at about 600°C*
- *on the surface of the steel present in the fire, a color appears indicating the temperature it were exposed to*

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Source: [12]

Plastics (synthetic polymeric materials)

- *modern construction materials*
- *a series of good properties*
- *biggest drawback, they intensively burn with the production of very dangerous combustion products*

In the Republic of Serbia, construction products and components are classified, using data from reaction to fire tests, according to the standard SRPS EN 13501-1: 2019

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FIRE TRACES

- *one side of the door is more burned*
- *traces at the joint between the window wings and the window frame*
- *during the fire, the glass parts of the door and windows are cracking or melting*
- *the glass parts are inserted into the grooves or not*
- *melting temperature of the glass is about 770°C*
- *glass breaking due to impact, fissures are much longer and more distinctive than those resulting from the heat, a star-like fracture*
- *layers of soot on the glass indicate whether the glass was broken before the fire or due to the fire*
- *during the thunder strike, round openings can be found on the glass and surrounding iron materials are magnetized*
- *latch of the lock is clean (not sooted) or not*
- *stacked sheets of paper or paper in a loose state*
- *the greatest deformations on the metal elements occur near the center of the fire*

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Traces in the vicinity of the fire site:

- *foot marks*
- *tire marks*
- *objects from the facility*
- *parts of the facility*
- *parts of the devices and installation*
- *containers in which flammable liquids for acceleration of the fire were kept*
- *intentionally left traces in order to mislead the investigator*

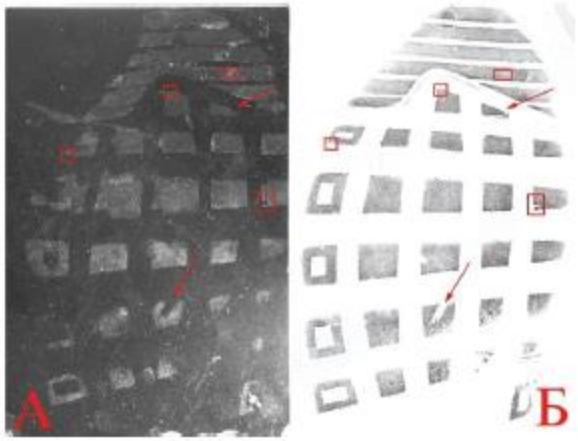
Traces of fire from the outside of the building:

- *a stack of soot above the holes (windows, doors), the so-called flue gases halo*

Traces on the inside of the building:

- *the place of the outbreak of the fire is determined by the degree of damage of the material that was in the fire, by comparing the damaged material with the material which the fire did not affect*

Слика 6. Предметна обућа одузета од осумњиченог лица и газећи профил леве патике са означеним индивидуалним карактеристикама



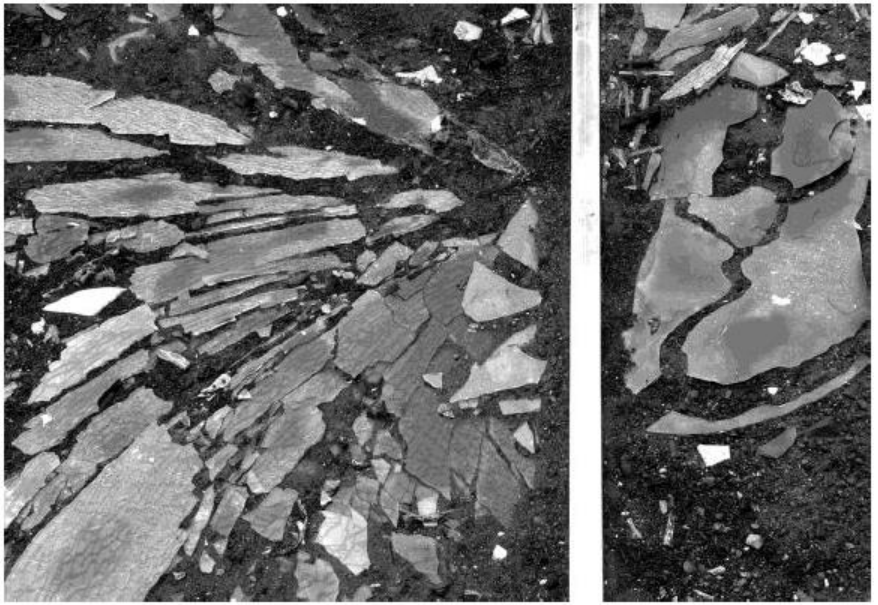
Слика 7. Траг обуће пронађен на лицу места (А) и пробни отисак леве предметне обуће са означеним идентификационим карактеристикама

Figure 6. Subject footwear taken from the suspect face and treadmill profile of the left sneakers with marked individual characteristics

Figure 7. The footprint found on the spot (A) and the test print of the left subject footwear with identified identification features

Kiurski, J. 2018. Priručnik za uviđaj. Beograd: Misija OEBS-a u Srbiji.

Source: [7]



Source: [7]

Source: [7]

ARSONS

- *highly flammable substances in the hot spot*
- *these substances are not normally located in such facilities*
- *fires caused by the candle (traces of paraffin, stearin, wax, wick, etc.) traces on both the suspected person and his/her clothes (easily flammable liquids, paraffin, stearin, wax)*
- *general traces on suspected person indicating his presence at the place of fire (earth, dust)*
- *Arsons are intentional or criminal fires that are caused by conscious or deliberate human activity.*
- *Motives are usually:*

1. *revenge (hurt pride, jealousy, envy)*
2. *self-interest (payment of insurance)*
3. *vanity*
4. *concealment of crimes (murder, theft)*

- *Arsons are often performed by persons in an alcoholic state, as well as by persons on the social and economic margin of society.*

Criminalistic division of the causes of fire:

- *natural (lightning, earthquake, solar energy)*
- *accidental - unintentionally caused by human guilt (children's play, cigarette but, failure to comply with fire protection measures, construction deficiencies - poor performance of electrical and gas installations, flue ducts)*
- *arsons (intentional or criminal fires)*

Reconstruction of the event occurs in cases where the investigation has not been thoroughly carried out and is performed in order to re-investigate all the circumstances under which the fire occurred.

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Source: [7]

Fire and arson are mentioned in the Criminal Code of the Republic of Serbia in the following articles:

- *204 (severe theft during fire)*
- *278 (causing general danger by fire for humans and property by acting or ignoring protection measures)*
- *285 (who does not report a fire or does not take remedial measures)*
- *286 (who acts in an unauthorized manner with flammable and explosive material)*
- *313 (jeopardizing of the constitutional order and state security through arson)*
- *326 (non-participation in the elimination of general danger)*
- *344a (bringing pyrotechnics, flammable, explosive materials to sports events and public gatherings)*
- *351 (abuse of the aid sign and danger sign)*
- *391 (causing fire out of terrorist initiatives)*
- *414 (theft of arms and a part of a combat agent)*

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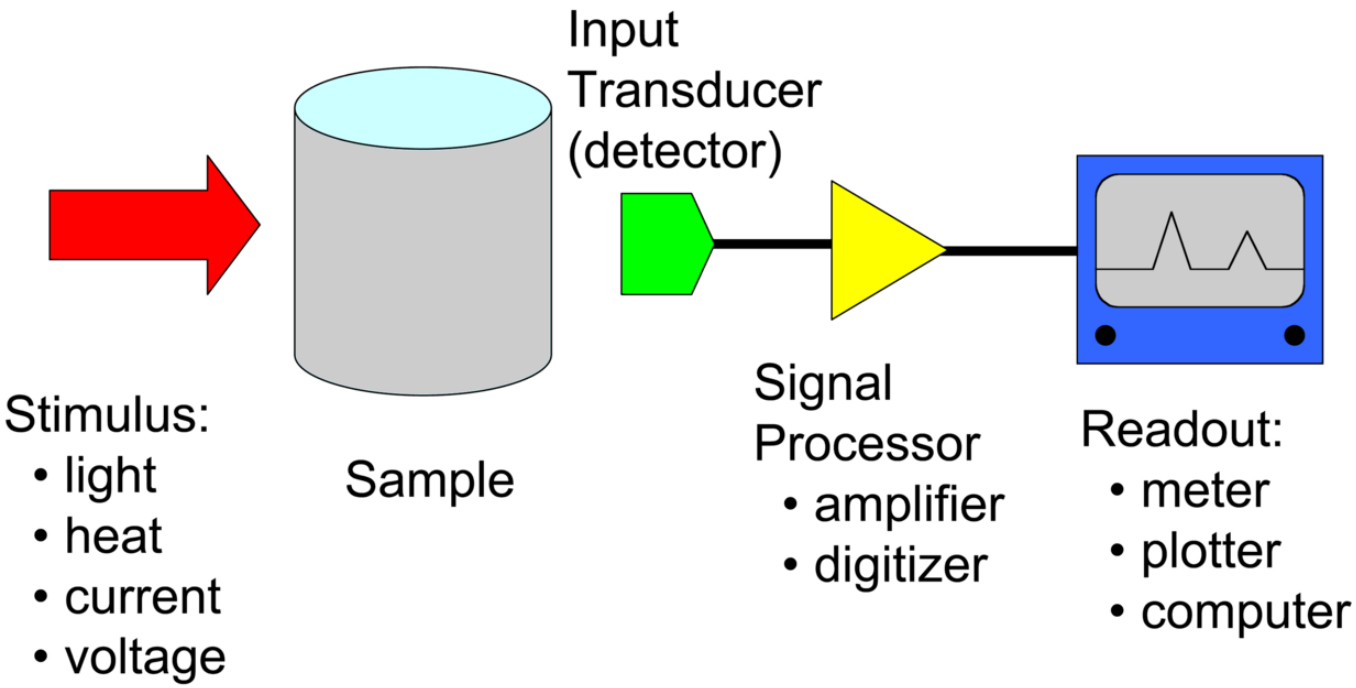
METHODS OF ANALYSIS IN THE EXPERT INVESTIGATION OF FIRE



Block diagram of an analytical instrument showing the stimulus and measurement of response, By Kkmurray - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=34745778

- *The physicochemical methods very accurately and precisely provide data on both the qualitative and the quantitative composition of the sample.*
- *Spectroscopic (spectrometric) methods are based on the interaction between matter and electromagnetic radiation.*
- *Depending on the origin of the radiation being examined (emitted, absorbed or reflected), the following is distinguished: emission, absorption and spectrum of reflected radiation (reflection spectra).*
- *Regarding the reflected-radiation spectrum, it should be kept in mind that the substance reflects those waves that it does not permeate and does not absorb.*
- *A set of waves of different wavelengths that a sample emits, absorbs or reflects, as well as its graphic scheme, is called a spectrum.*
- *Each spectrum of electromagnetic radiation carries information on the chemical composition of the substance that emits it, absorbs it or reflects it.*

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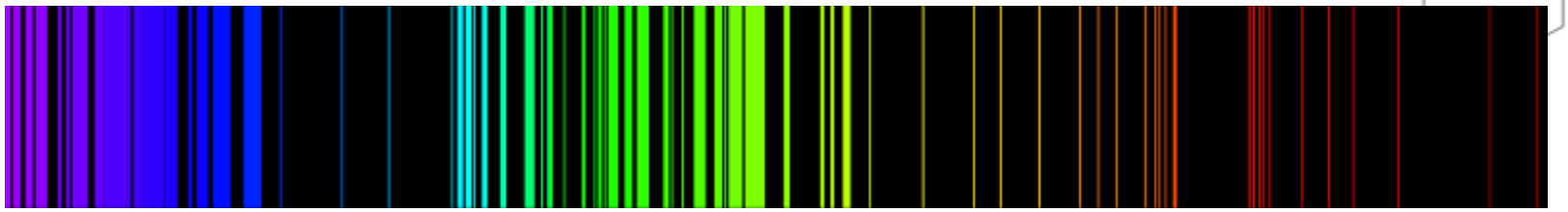
Emission spectrum of hydrogen, https://commons.wikimedia.org/wiki/File:Emission_spectrum-H.svg#/media/File:Emission_spectrum-H.svg, 02.05.2019.



Emission spectrum of iron, https://commons.wikimedia.org/wiki/File:Emission_spectrum-Fe.svg#/media/File:Emission_spectrum-Fe.svg, 02.05.2019.

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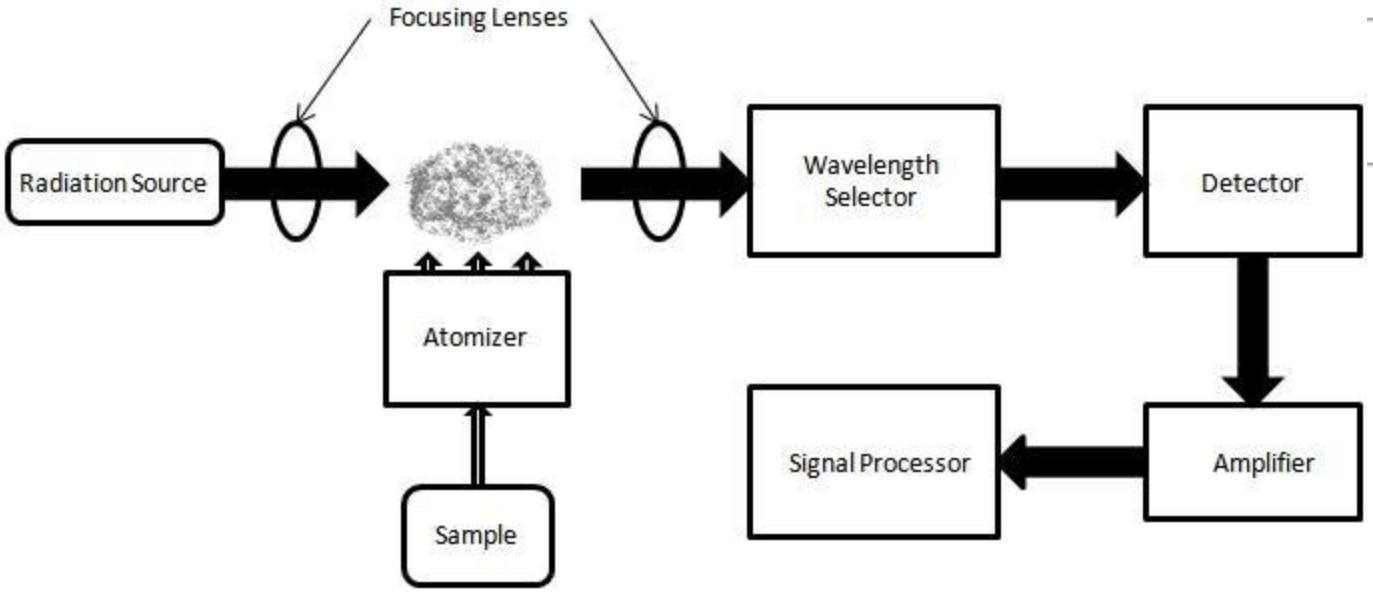
Atomic Absorption Spectrometry

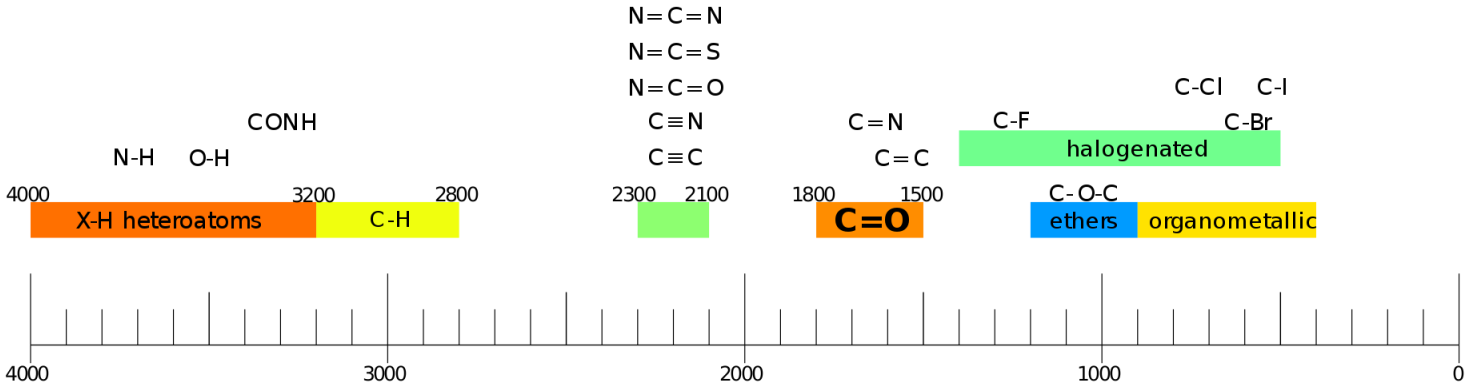


Atomic absorption spectrometer block diagram, By K05en01 - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=5177835, 02.05.2019.

Flame atomic absorption spectroscopy instrument, https://commons.wikimedia.org/wiki/File:FlammenAAS.jpg#/media/File:FlammenAAS.jpg, 02.05.2019.

Infrared spectrometry

Infrared spectrometry is used in criminalistic technique to identify various substances of organic origin such as: drugs, explosives, petrol, petroleum and other fuels, grease, adhesives, various poisons, insecticides, paints, varnishe.



List of main IR spectroscopy bands. For example, the carboxyl group will contain a C = O band at 1700 cm^{-1} and an OH band at 3500 cm^{-1} (total group -COOH). Wavenumbers listed in cm^{-1}, https://commons.wikimedia.org/wiki/File:IR-spectroscopy-sample.svg#/media/File:IR-spectroscopy-sample.svg, 02.05.2019.

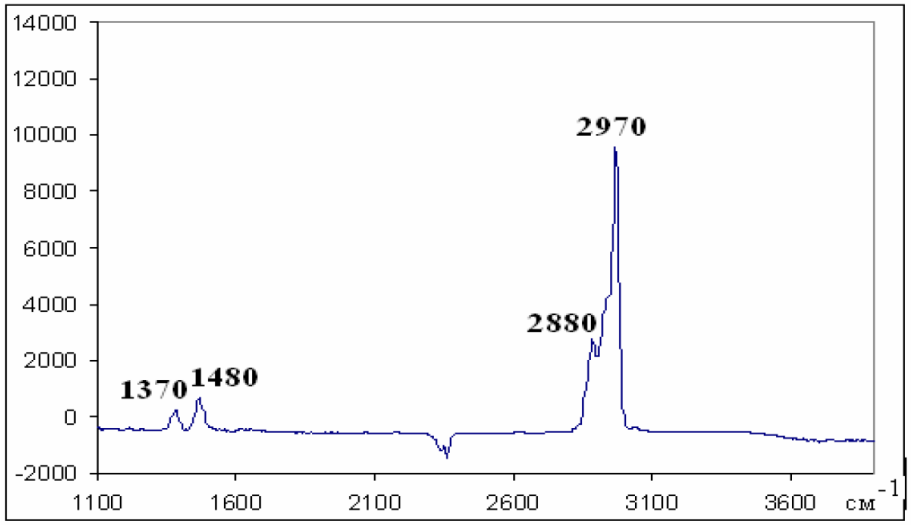


Рис. 55 ИК-спектр автомобильного бензина

IR spectrum of gasoline [18]

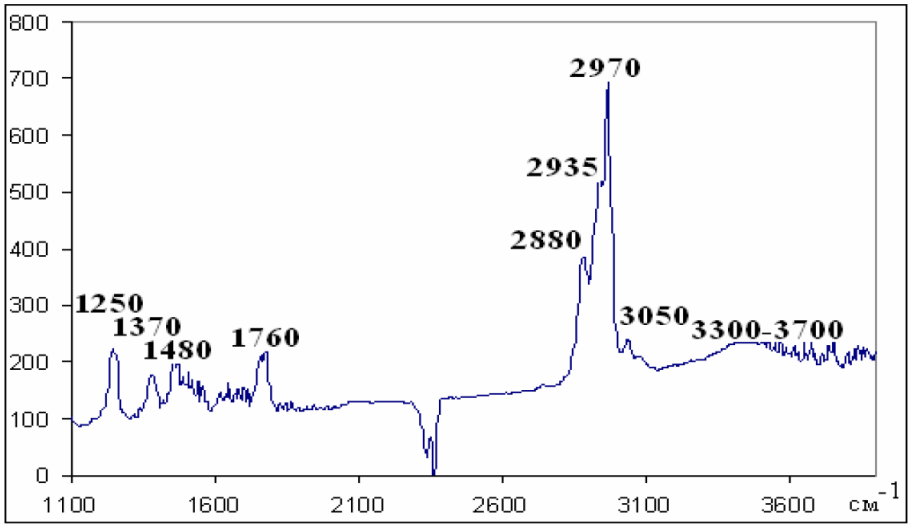
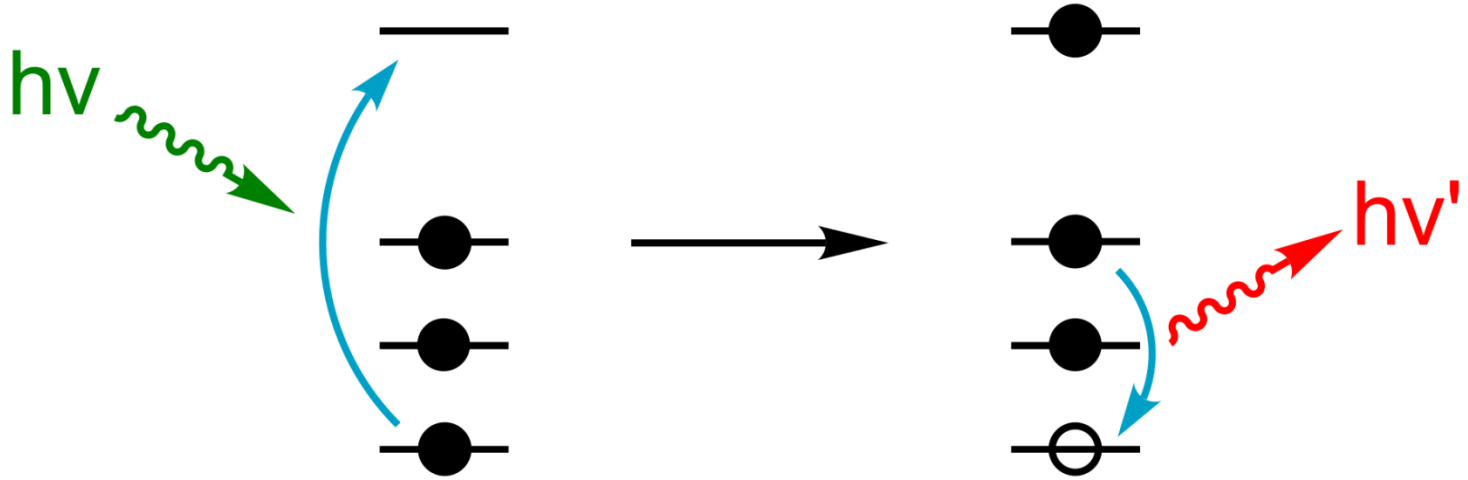


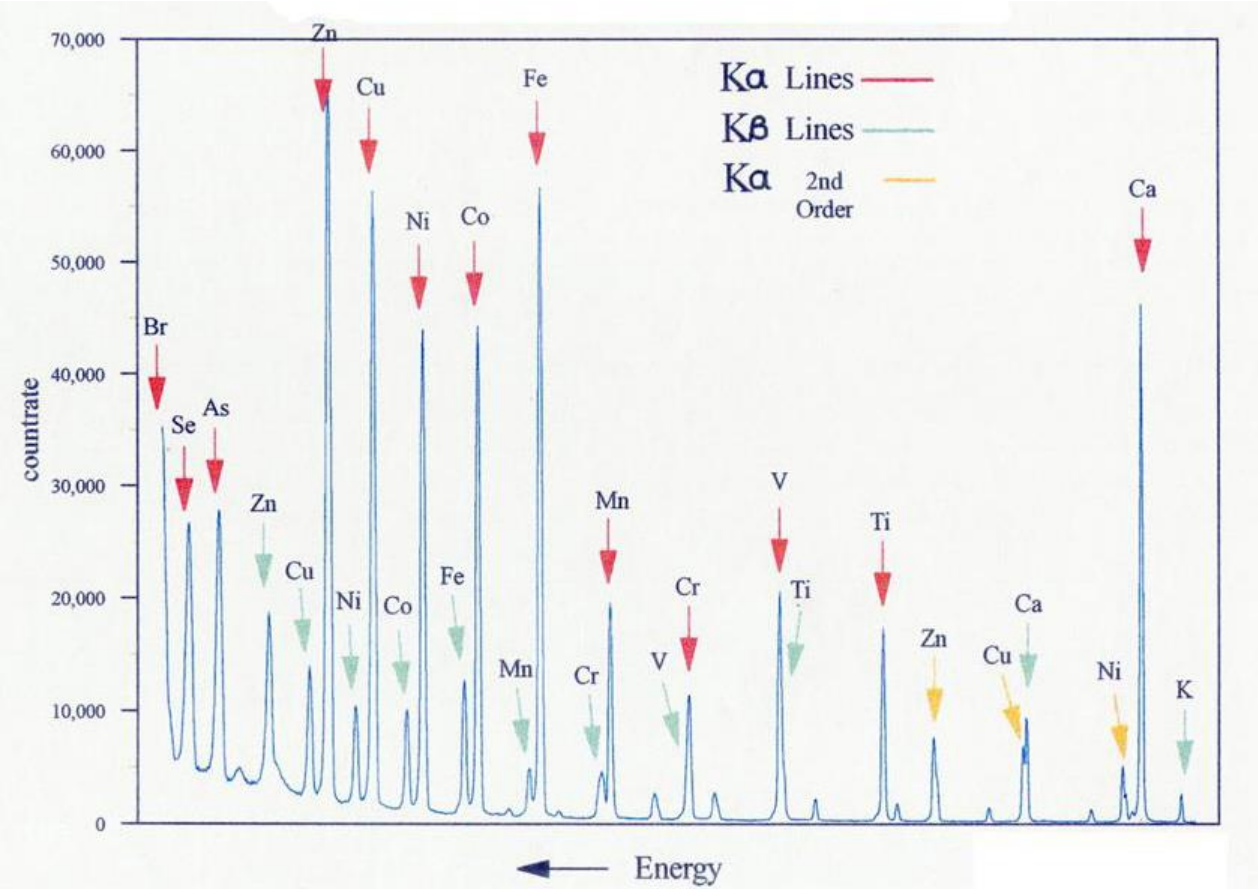
Рис. 56 ИК-спектр дизельного топлива

IR spectrum of diesel fuel [18]

X-ray fluorescence analysis



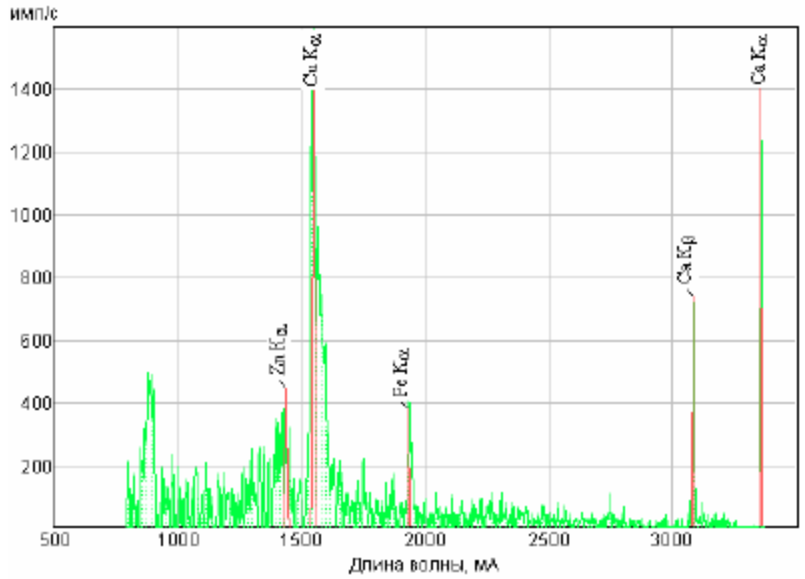
Physics of X-ray fluorescence in a schematic representation, https://commons.wikimedia.org/wiki/File:X-ray_fluorescence_simple_figure.svg#/media/File:X-ray_fluorescence_simple_figure.svg, 02.05.2019.



Typical wavelength dispersive XRF spectrum, https://commons.wikimedia.org/wiki/File:XRFScan.jpg#/media/File:XRFScan.jpg, 02.05.2019.

РФА применяется при поиске следов применения поджигающих составов на основе сильных окислителей, компоненты которых в основном представляют собой неорганические вещества, различные металлы, их оксиды и соли. Их наличие в спектрах РФА образцов изымаемых с места пожара, в случае если они не присутствуют в исходных материалах, свидетельствует о возможном поджоге. Например, на рисунке 54 представлены спектры РФА ковролина исходного и сожженного под действием осветительной ракеты. Привнесение в материал таких элементов, как барий и стронций говорит о присутствии в образце продуктов горения данного пиротехнического изделия.

X-ray fluorescence analysis is used in the criminalistic technique for the analysis of pure metals, alloys, various mineral substances, powder materials, molten materials, liquids, various substances of organic origin.



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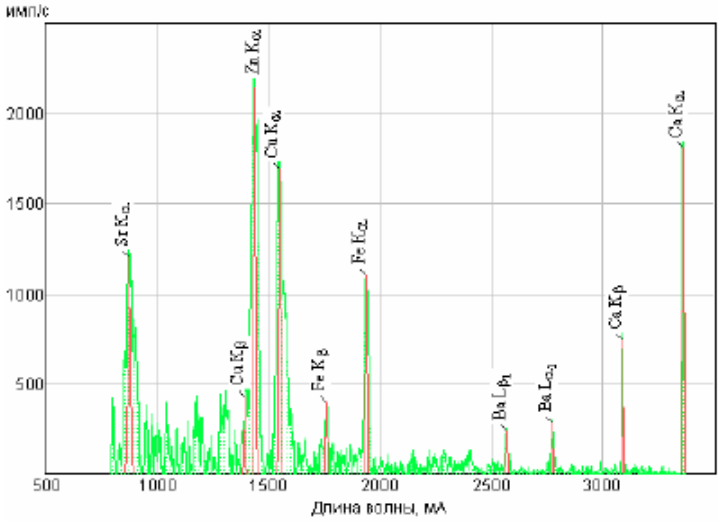

б

Рис. 54 Спектры РФА исходного ковролина (а) и ковролина сожженного под действием осветительной ракеты (б).

A synthetic carpet XRF-spectrum without traces of the pyrotechnic agent (a), or with the traces of the pyrotechnic article (b), the barium and the strontium are the components of the pyrotechnic agent [18].

X-ray diffraction analysis

Each crystalline substance has its own specific arrangement and intensity of the traces of diffraction, which means that, based on the appearance of the diffraction image, each crystalline substance can be identified individually. Unlike spectral methods, with the help of which the identification of the individual elements from the composition of the material traces is performed, by the method of the X-ray diffraction analysis the identification of chemical compounds is done. It is used as a supplement to spectral analysis, especially when it is necessary to determine the composition of the most complex chemical compounds. It is used to distinguish the primary from the secondary short circuit.

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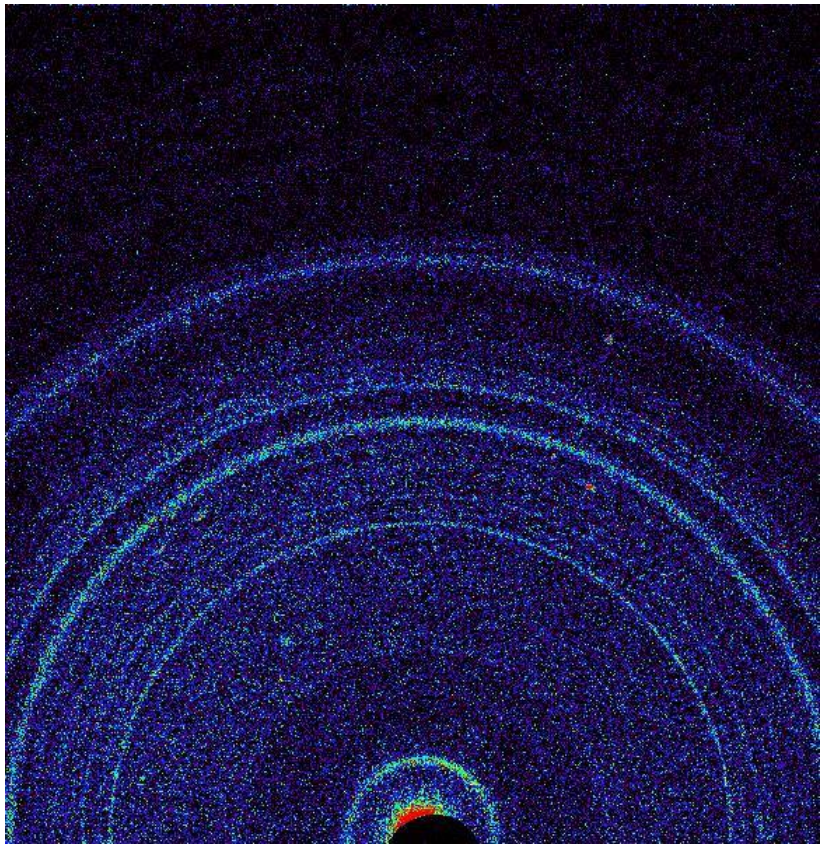
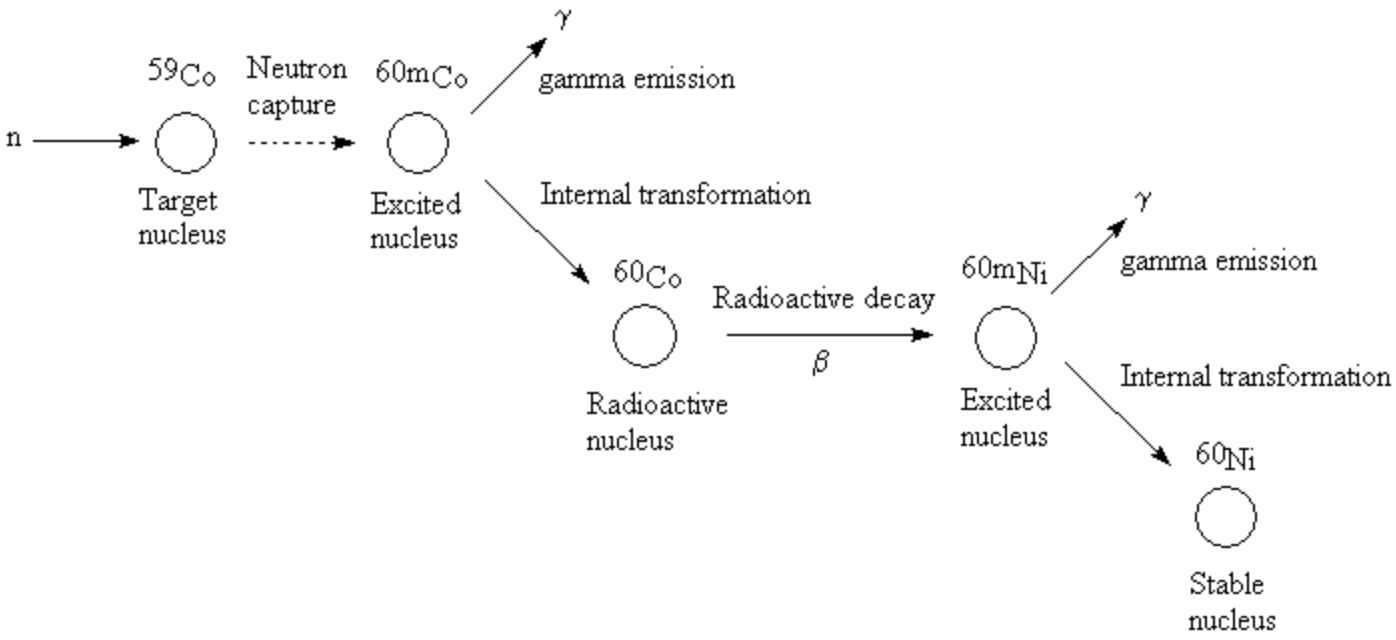


First X-ray diffraction view of Martian soil – CheMin analysis reveals feldspar, pyroxenes, olivine and more (Curiosity rover at "Rocknest", October 17, 2012). https://commons.wikimedia.org/wiki/File:PIA16217-MarsCuriosityRover-1stXRayView-20121017.jpg#/media/File:PIA16217-MarsCuriosityRover-1stXRayView-20121017.jpg, 02.05.2019.

10.30.2012 First X-ray View of Martian Soil http://photojournal.jpl.nasa.gov/catalog/PIA16217 This graphic shows results of the first analysis of Martian soil by the Chemistry and Mineralogy (CheMin) experiment on NASA's Curiosity rover. The image reveals the presence of crystalline feldspar, pyroxenes and olivine mixed with some amorphous (non-crystalline) material. The soil sample, taken from a wind-blown deposit within Gale Crater, where the rover landed, is similar to volcanic soils in Hawaii. Curiosity scooped the soil on Oct. 15, 2012, the 69th sol, or Martian day, of operations. It was delivered to CheMin for X-ray diffraction analysis on October 17, 2012, the 71st sol. By directing an X-ray beam at a sample and recording how X-rays are scattered by the sample at an atomic level, the instrument can definitively identify and quantify minerals on Mars for the first time. **Each mineral has a unique pattern of rings, or "fingerprint," revealing its presence.** The colors in the graphic represent the intensity of the X-rays, with red being the most intense. Image Credit: NASA/JPL-Caltech/Ames

Neutron activation analysis



Nuclear processes occurring when cobalt is irradiated with neutrons, https://en.wikipedia.org/wiki/File:Neutronactivationscheme.png#/media/File:Neutronactivationscheme.png, 02.05.2019.

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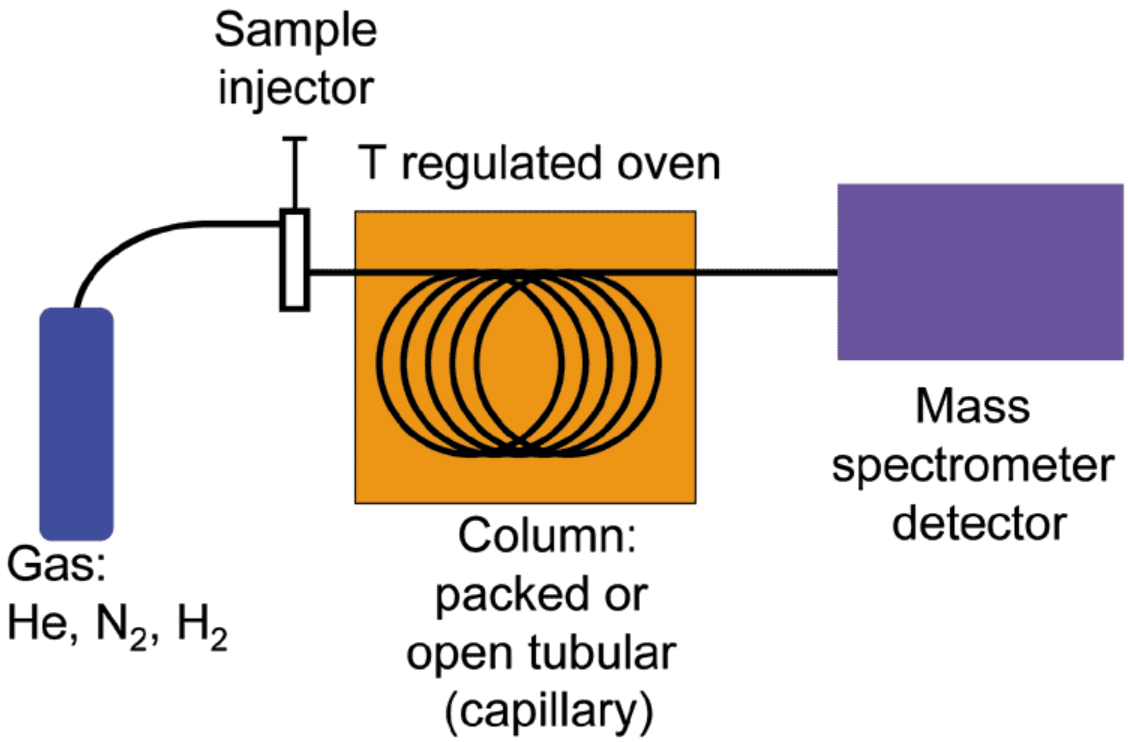
NAA can detect up to 74 elements depending upon the experimental procedure, with minimum detection limits ranging from 0.1 to 1x10^{6} ng g^{-1} depending on element under investigation. Heavier elements have larger nuclei, therefore they have a larger neutron capture cross-section and are more likely to be activated. Some nuclei can capture a number of neutrons and remain relatively stable, not undergoing transmutation or decay for many months or even years. Other nuclei decay instantaneously or form only stable isotopes and can only be identified by PGNAA. Neutron Activation Analysis has a wide variety of applications including within the fields of archaeology, soil science, geology, forensics, and the semiconductor industry. Forensically, hairs subjected to a detailed forensic neutron analysis to determine whether they had sourced from the same individuals was first used in the trial of John Norman Collins, https://en.wikipedia.org/wiki/Neutron_activation_analysis, 02.05.2019.
In criminalistic laboratories of highly developed countries, it is widely used for determining the distance of shooting, identifying the human hair, as well as for determining the presence of an element in samples of different traces.

Gas chromatography



GC-MS schematic, https://commons.wikimedia.org/wiki/File:Gcms_schematic.gif#/media/File:Gcms_schematic.gif, 02.05.2019.

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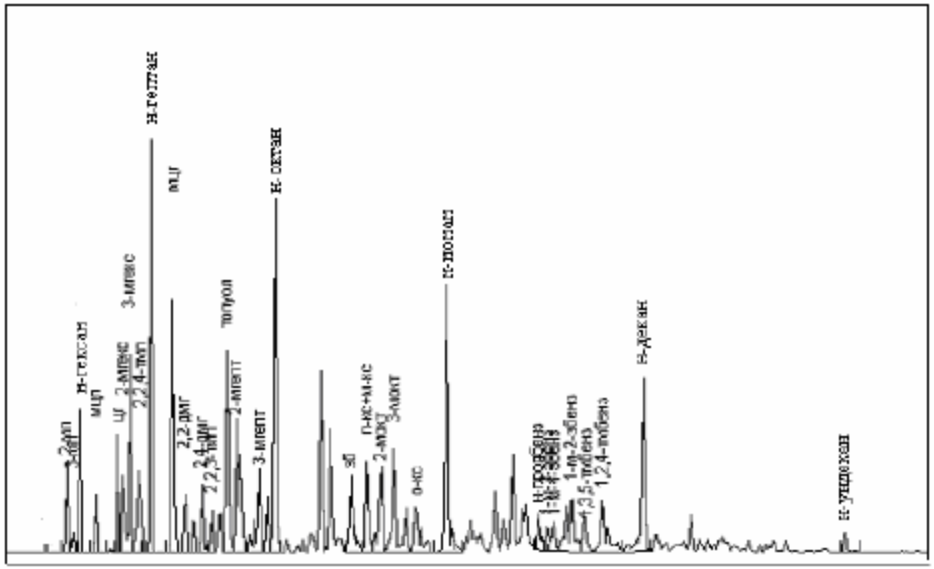


Рис. 63 Хроматограмма прямогонного бензина АВТ-52 новокуйбышевского НПЗ

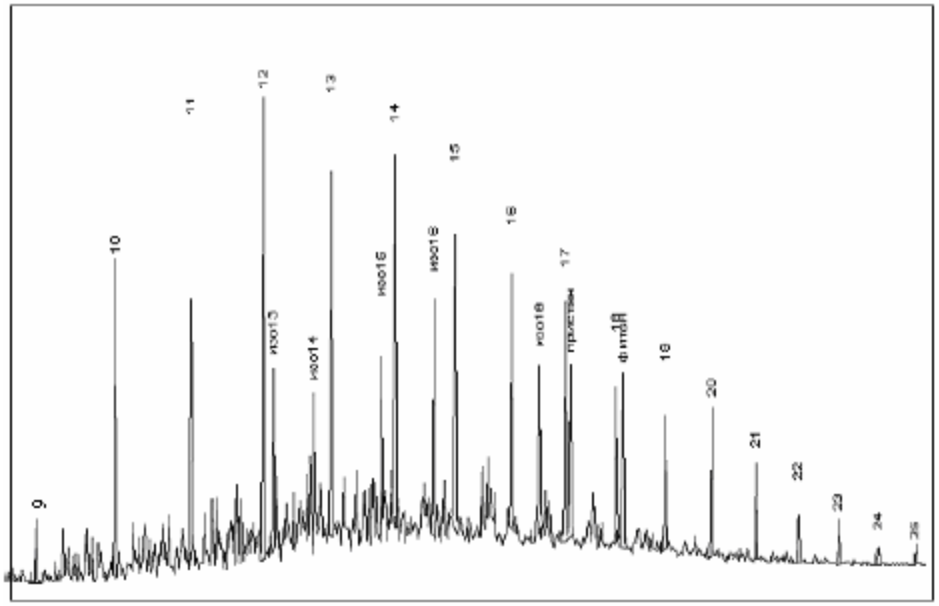
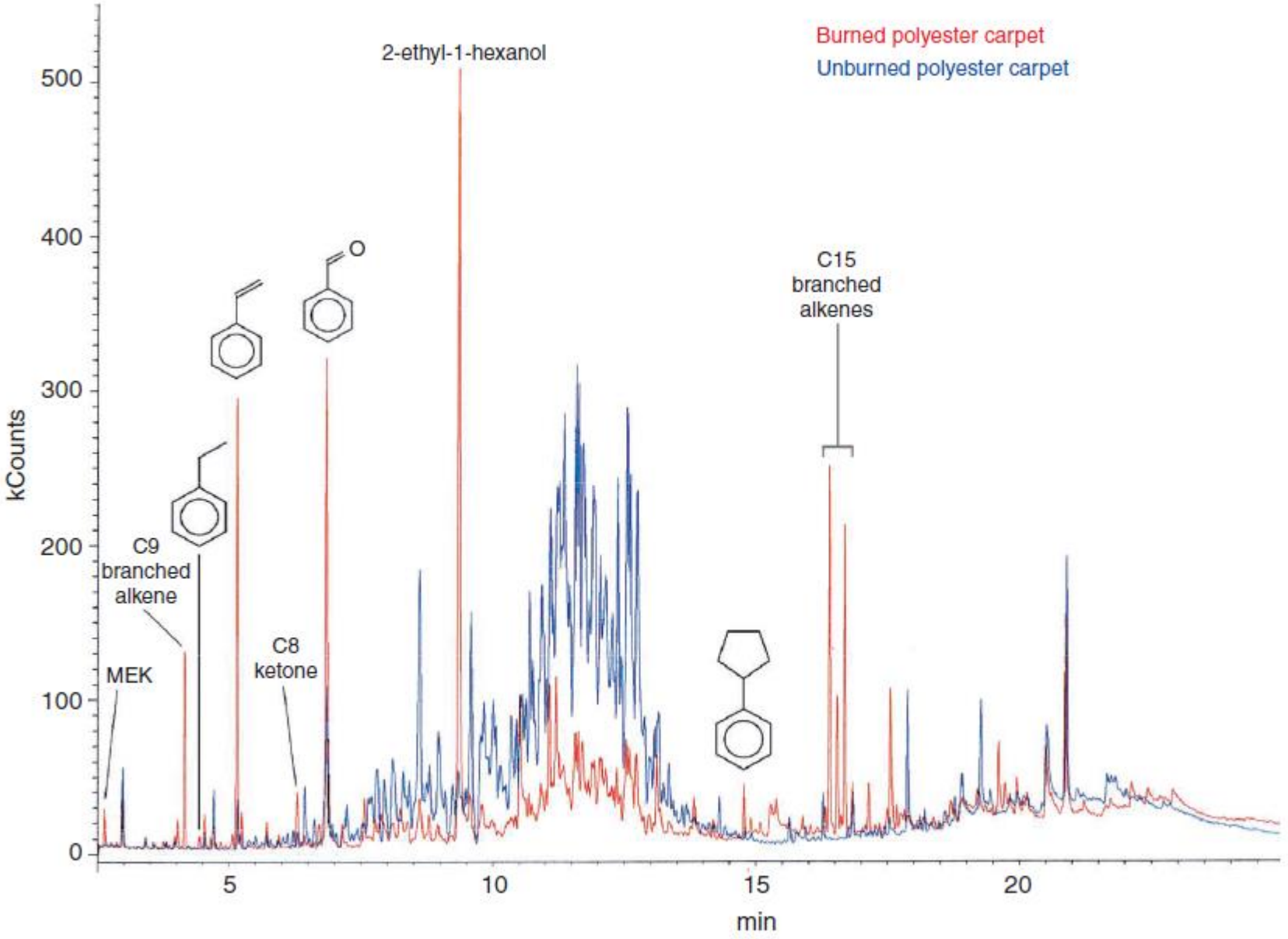


Рис. 64 Хроматограмма дизельного топлива

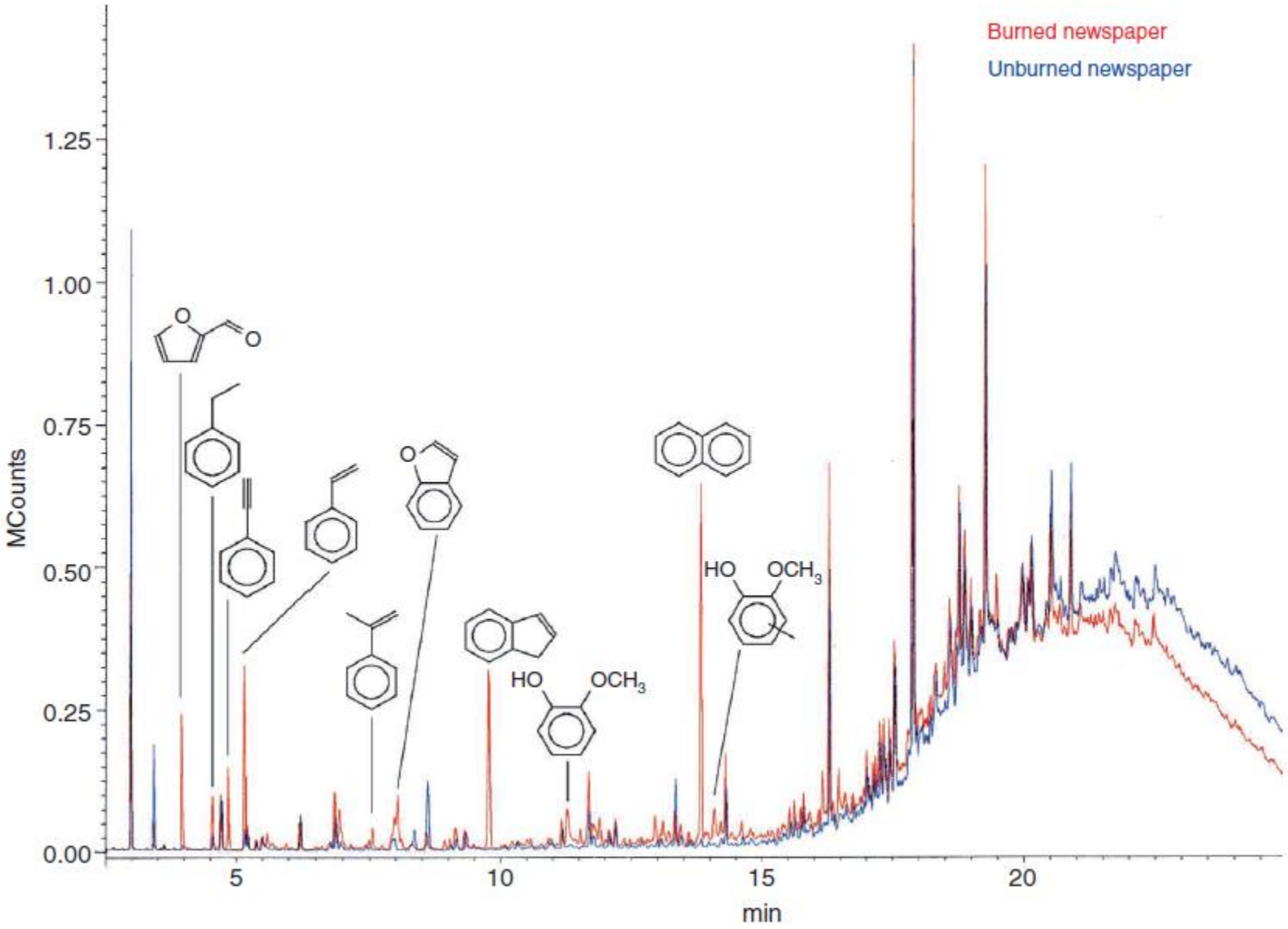
Chromatogram of the gasoline (Figure 63), and the diesel fuel (Figure 64) [18]

In the criminal investigation, materials of different origin can be analyzed using the gas chromatography method, and this method is most often used for toxicological analyzes of various drugs, narcotics, pesticides and other poisons, as well as for determining the composition of traces of fires, explosives, fats, oils .



Colour Plate I The chromatograms of burned and unburned polyester carpet (see Figure 7.9, p. 209)

Source: [19]



Colour Plate II The chromatograms of burned and unburned newspaper (see Figure 7.10, p. 210)

Source: [19]

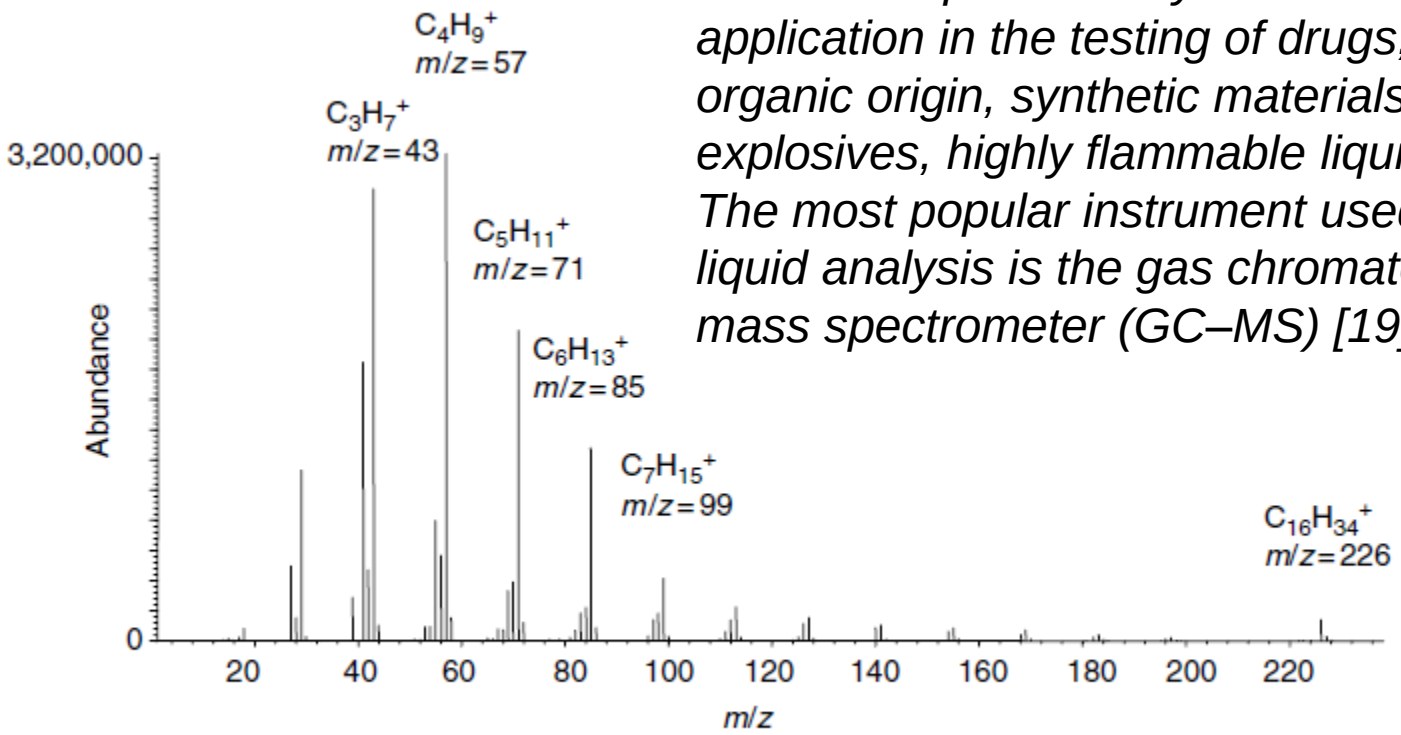


Figure 6.5 Mass spectral data illustrating the fragmentation of hexadecane (C16)

The mass spectrometry method has wide application in the testing of drugs, poisons of organic origin, synthetic materials, fibers, explosives, highly flammable liquids.
The most popular instrument used for ignitable liquid analysis is the gas chromatograph–mass spectrometer (GC–MS) [19].

Source: [19]

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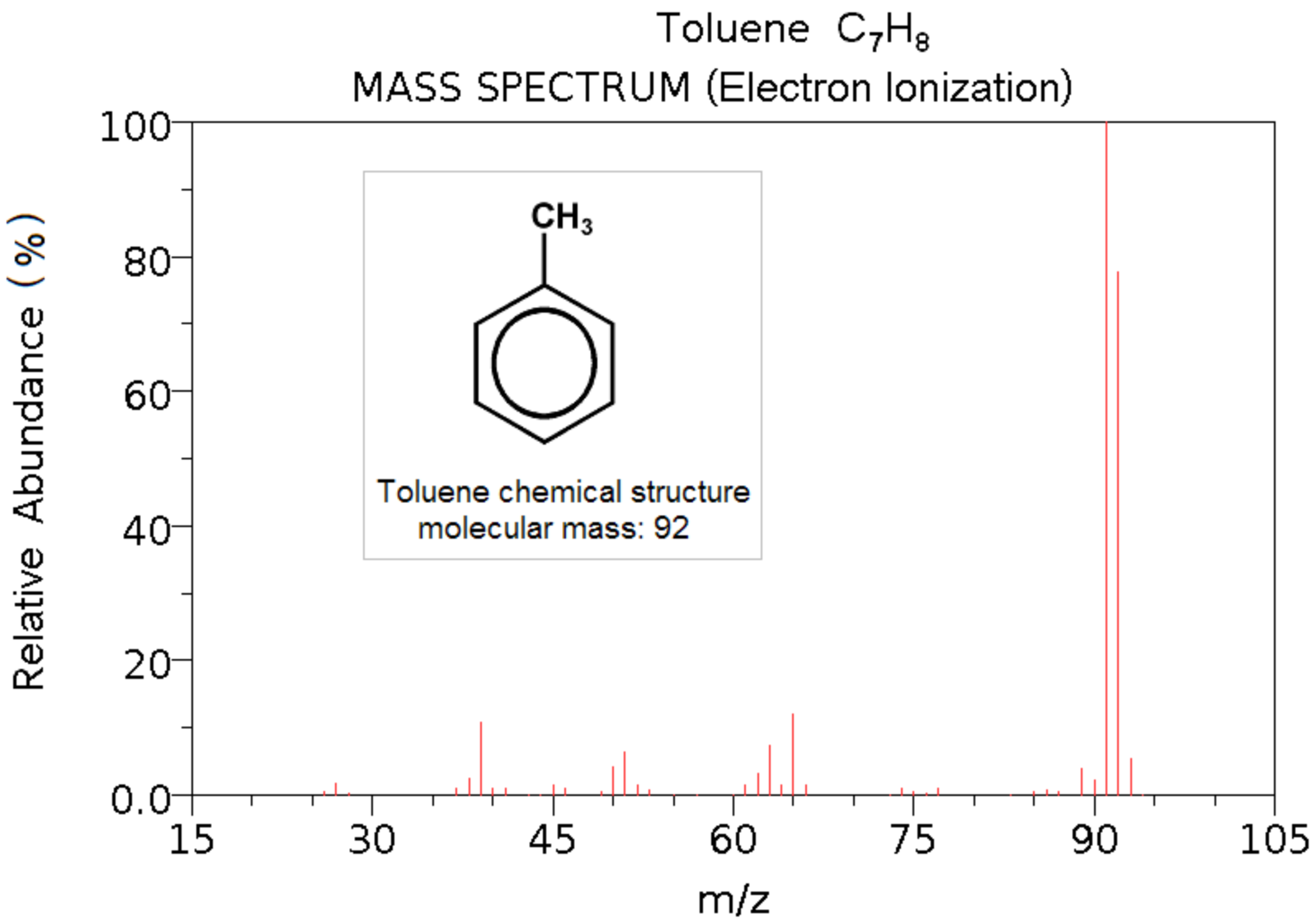

Toluene electron ionization mass spectrum, https://commons.wikimedia.org/wiki/File:Toluene_ei_ms.PNG#/media/File:Toluene_ei_ms.PNG, 02.05.2019.

Analysis of the DNA (deoxyribonucleic acid) residues of bones, teeth, hairs and similar cellular material

It is a very delicate process to identify dead bodies which are mostly, or completely, carbonized. High temperatures destroy most of the identification features of the human body, so at present the method of analysis of the DNA is applied .

DNA profiling is a forensic technique in criminal investigations, comparing criminal suspects' profiles to DNA evidence so as to assess the likelihood of their involvement in the crime. Although 99.9% of human DNA sequences are the same in every person, enough of the DNA is different that it is possible to distinguish one individual from another, https://en.wikipedia.org/wiki/DNA_profiling, 02.05.2019.

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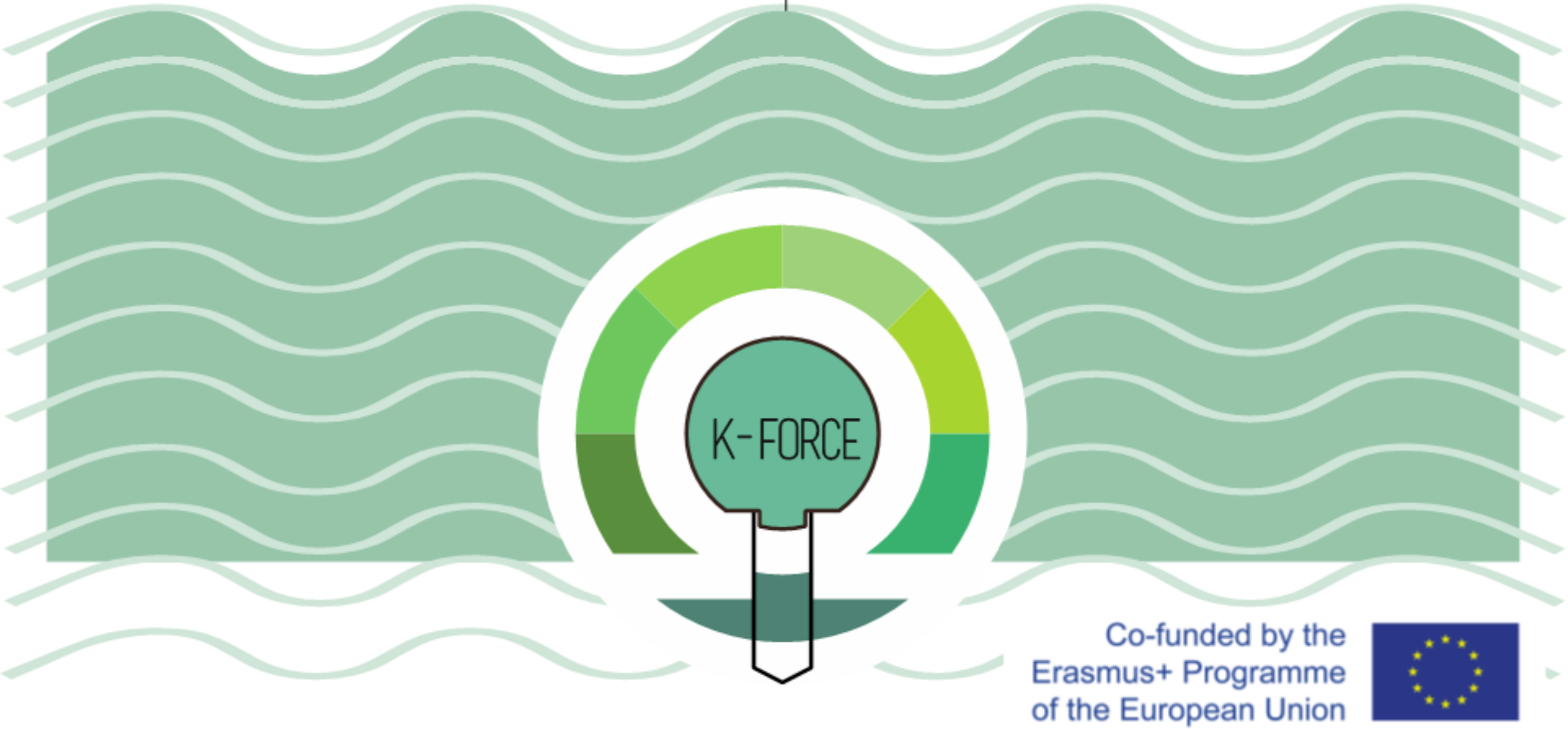

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spaic@vtsns.edu.rs

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