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The Scientific Department of the National Gallery

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Introduction

Ideally all the many activities of a museum or art gallery should be reflected in its scientific department, for its purpose is to bring science to the service of the museum, and scientific knowledge properly used can be of service in most activities.

Thus, most obviously science ought to be able to take a major part in helping the museum to perform its task of guarding the exhibits by specifying and monitoring the museum climate. It should also widen the historical scope of the curatorial staff by providing information on the technical history of the collection: the methods and materials used. The story of the use of science in museums will, however, lay the greatest emphasis on chemical and physical analysis and on the use of new methods in restoration. Both of these produce immediate results of obvious benefit. Indeed one could say that analysis will remain the foundation activity, since on it depends, not only our knowledge of the composition of any particular exhibit, but also our hope of understanding its weaknesses and of relating its technical history to that of other exhibits.

The common pitfall is that the staff of a museum scientific department, in response to calls from various directions, turn from one to the other and are never able to get down to the sustained work which is so badly needed.

To avoid this without swelling the size of the laboratory staff until it is out of balance with the rest of the museum, activities must be limited and defined. A choice must be made which will depend to quite a large extent on the particular capabilities of the staff.

Scientific research has become increasingly capital-intensive. There are instruments which can pour out results faster than human beings can possibly assimilate them. But with an able and imaginative staff who have more problems than they can ever tackle unaided this is a good situation to make use of. A well-equipped laboratory with a small but capable staff can be immensely productive.

The general strategic aims of a museum laboratory can then be expressed as follows:

To bring the resources of science to bear on those aspects of museum work which can benefit from them;

yet by limiting and defining goals, to avoid diffusion of effort in too many directions;

and, since none but the very largest museums can accommodate a laboratory of the size usually regarded as viable, to aim for a higher than average standard of research ability, backed by high-quality equipment.

Origin of the Scientific Department

The Scientific Department was established in the National Gallery in 1934 with the appointment of a Scientific Adviser, F. I. G. Rawlins, who was also instructed to act as Supervisor of Publications.

At that time there was renewed interest in the contribution which science could make to art, but we should not forget that this interest had been very much alive in the middle of the nineteenth century, when the National Gallery had had a brief encounter with no less a scientist than Michael Faraday. In 1850 and 1853 two august Select Committees were appointed by the House of Commons to enquire into the management of the Gallery, and Faraday's opinion was sought on a subject very close to our present enquiries: the effects on the paintings of the heavily polluted atmosphere in the neighbourhood. When it was suggested that it might be a good thing if he were to devote himself professionally to such investigations he replied that, whilst he himself could not take on the task, he had 'no doubt that a person of competent chemical knowledge and a little acquainted with paintings in ancient and modern times might be valuably employed in ascertaining such points'. Regrettably Faraday's advice went unheeded for 80 years.

By the 1930s the emphasis had swung from basic enquiries concerning preservation to the scientifically more facile process of looking through paintings with X-rays. But soon science and technology were to become much more closely relevant to preservation. Before the Second World War the first Scientific Adviser had tried unsuccessfully to persuade the National Gallery Trustees of the importance of air conditioning with humidity control. On the outbreak of war and with the evacuation of the National Gallery collection to a slate quarry in North Wales, air-conditioning abruptly changed from what some had thought to be a luxury to a prime necessity: the relative humidity in the slate quarries was close to 100 per cent all the year round. Heating alone brought this down to 58 per cent, and the dramatic reduction in all the troubles caused by detachment of paint gave strong impetus to the introduction of air conditioning in the exhibition rooms after the war.

Of course the combination of scientific work with supervision of publications and of photography could not last as all three activities grew, so that shortly after the War (in 1949) a manager was appointed for publications and photography, and at the same time all routine X-ray, infra-red and ultra-violet photography was passed to the photographers.

Figure 1. The Northern Extension to the National Gallery, opened in June 1975. The new quarters of the Scientific Department occupy the top northern end of this extension, seen here as a line of windows over the entrance. Architect: D. Church, Dept. of the Environment.

The Honorary Scientific Advisory Committee

A year after the appointment of the first Scientific Adviser an Honorary Scientific Advisory Committee was created and held its first meeting in 1935. Two founder-members were Dr. Harold Plenderleith, then head of the British Museum Research Laboratory, and Sir William Bragg, a prominent Fellow of the Royal Society. The Committee was later enlarged, and has always included several prominent scientists.

As the Scientific Department approaches the end of its first half-century it is instructive to note how, during this time, the profession of conservation scientist has developed not one but several special fields of knowledge. Yet on the creation of the HSAC the general feeling must have been that science could best be made use of by, as it were, funnelling the knowledge of scientists pre-eminent in other fields into the museum through the Scientific Adviser.

In the course of time the real uses of the HSAC became apparent, especially after close links were established with the Board of Trustees of the National Gallery. From then on one could ensure that there was a free and reliable exchange of information on long-term policy and other general scientific matters. The members of the HSAC have also provided essential access not only to their own establishments but to others with the knowledge to help in particular problems, and have been invaluable in helping to organize outside scientific work for the Gallery.

Finally, lest anyone setting up a museum laboratory should suppose that museum science can be carried out or even directed by scientists working in other fields, it must be emphasized that the HSAC, as its name implies, limits itself to advice.

Development

One or two readers may recall the furore when the cleaning of discoloured varnishes from paintings and their replacement with clear varnishes began to find critics. The need was to present very clearly the evidence for the safety and high standard of the techniques used in restoration, and to have this evidence sifted by an impartial body of outside experts.

In 1947 the Weaver Committee was set up for this purpose, and gave direct benefit to scientific work by making one of its recommendations the enlargement of the Scientific Department staff.

Thus began what has become the most generally interesting and productive branch of the Department's work: the analysis of the materials of paintings. Originally this meant analysis of pigments by small-scale chemical analysis and the preparation of paint micro-cross-sections. But it soon broadened to include the organic materials of paintings, in particular the drying-oil paint media and natural-resin varnishes. Basic research included a complete identification of the chemical constituents of dammar resin.

In 1975 the Department moved to its present site: the top floor of the new northern extension to the Gallery (Figs.1,2).

The present

Today the Scientific Department comprises a staff of six, who works in pairs on three fields. In historical order of development these are: inorganic analysis and microscopy, organic analysis, and research on the effect of the environment.

The reader will note that this is a small sample of the whole field. There is at the moment no sustained research, for example, on the materials of restoration or on technical methods of photographic examination. But the policy is not to over-diffuse limited resources. Nevertheless the advice given by the laboratory certainly extends into other fields where it holds some competence. Work has been done in the recent past on varnishes, and the laboratory now runs the de Boer type of infra-red imaging on closed-circuit TV, to mention two examples.

Microscopy

Because microscopy is the first need of most museum research laboratories and perhaps the only possibility for many museums, this part of the work is described in rather greater detail.

Optical and chemical microscopy has been a feature of the Department's work since the institution of a chemical laboratory in 1949. At that time the space allotted to the subject was virtually a cupboard under the stairs, it occupied one member of staff half-time and throughout the 1950s and early '60s most of the work was done on an 1895 Leitz brass microscope (which we still have and sometimes use, its optical system as good as ever). Photomicrography was done by balancing a box camera precariously over the tube of the monocular microscope, waiting for the vibration to die down, then guessing the exposure. In the new department micro-

copy is spread over three rooms, occupies two persons full time and, over the years, as the need has arisen and as funds have become available, a comprehensive range of apparatus has been systematically acquired.

By means of a combination of microscopical examination and chemical tests (carried out either under the microscope or as 'spot tests' on drops of the solution of the pigment on filter paper or porcelain spot plates) the majority of artists' pigments can be identified in very small samples. Some mineral pigments can be identified with certainty, given only a few grains, solely from their particle characteristics and optical properties (e.g. refractive indices, birefringence). The optical microscope is also used for identifying species of wood of panel paintings and textile fibres of canvases. We have found though, that its greatest value lies, in the case of paintings, in the elucidation of the layer structure. For this purpose a minute flake of paint, no more than about 0.5mm diameter, is removed from the picture and after a preliminary microscopical examination is embedded in a block of transparent plastic. One face of the block is ground down until the edge of the paint flake is exposed then grinding and polishing is continued until the surface is sufficiently smooth and flat to focus under the microscope. The sequence of layers—the ground (or layer of preparation), the drawing and undermodelling, the various paint layers, glazes and final varnish and, sometimes later overpaint—are clearly seen at magnifications about 100–300×. In practice such samples are taken only when a picture is undergoing cleaning and restoration and if microscopical examination or chemical analysis of samples might help to solve some of the problems of diagnosis and treatment. Even then sampling is confined to areas of existing damage or to edges of the picture. While the picture is in the conservation studio, however, under ideal conditions for examination, opportunity is taken to look at the materials, condition and technique of the painting as a whole. Afterwards the prepared paint cross-sections and other samples are stored away with their accompanying data and have gradually been built up into a reference library of painters' materials and techniques. It is now possible, for example, to take and compare paint cross-sections from more than twenty different paintings by Rembrandt or Tintoretto.

The new *Microscope Room* is a comparatively spacious squarish room with benches and storage cabinets running round the walls. A narrower, more compact room, like the Microchemical Laboratory might have been preferred but the size and the shape of the present room is dictated by the need to accommodate from time to time as many as twenty people for talks and demonstrations and also to house the extensive collection of reference samples mentioned above. The largest and most-used microscope, a Leitz 'Ortholux' research model, occupies the most prominent position (Fig.3).

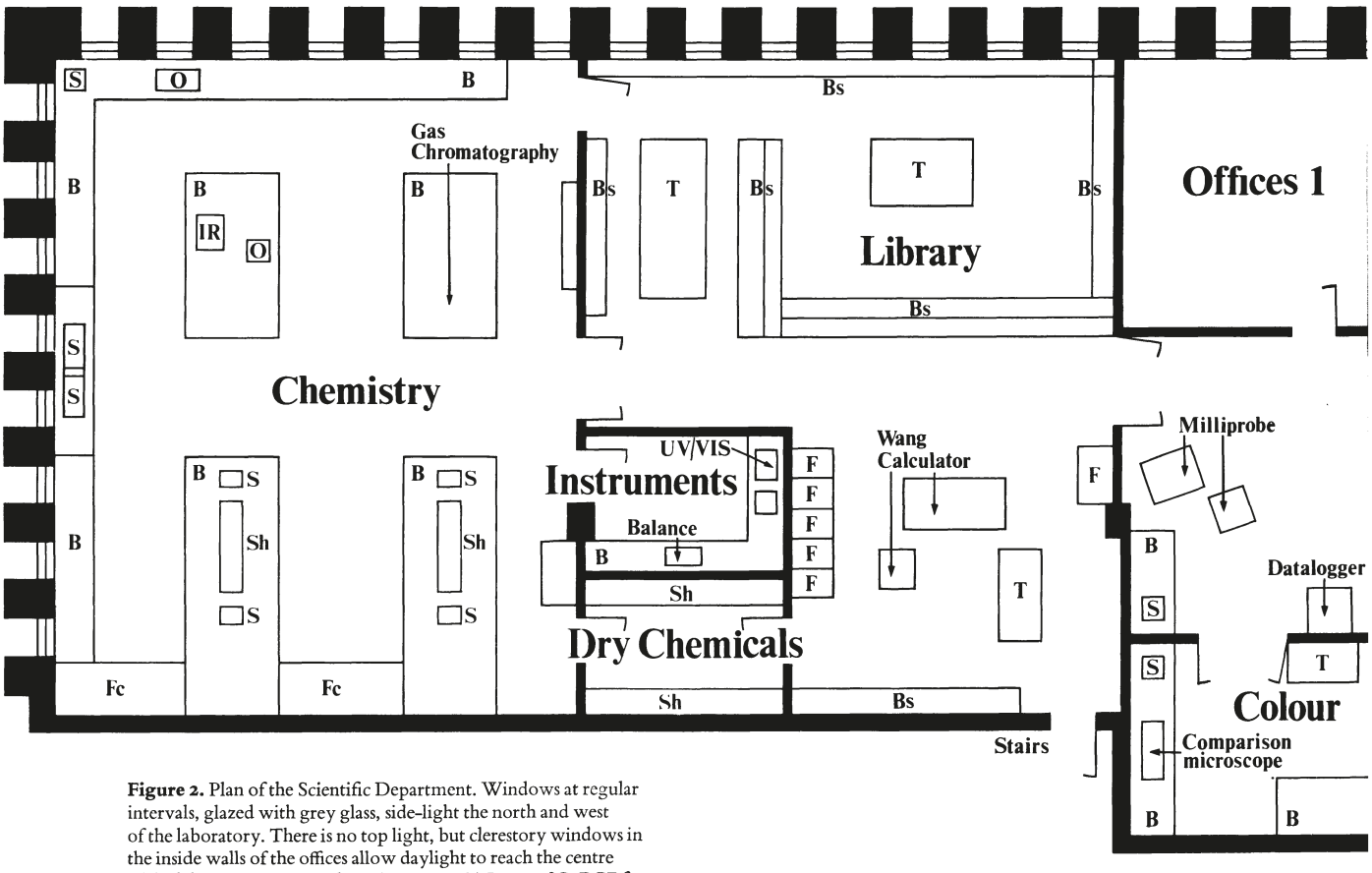
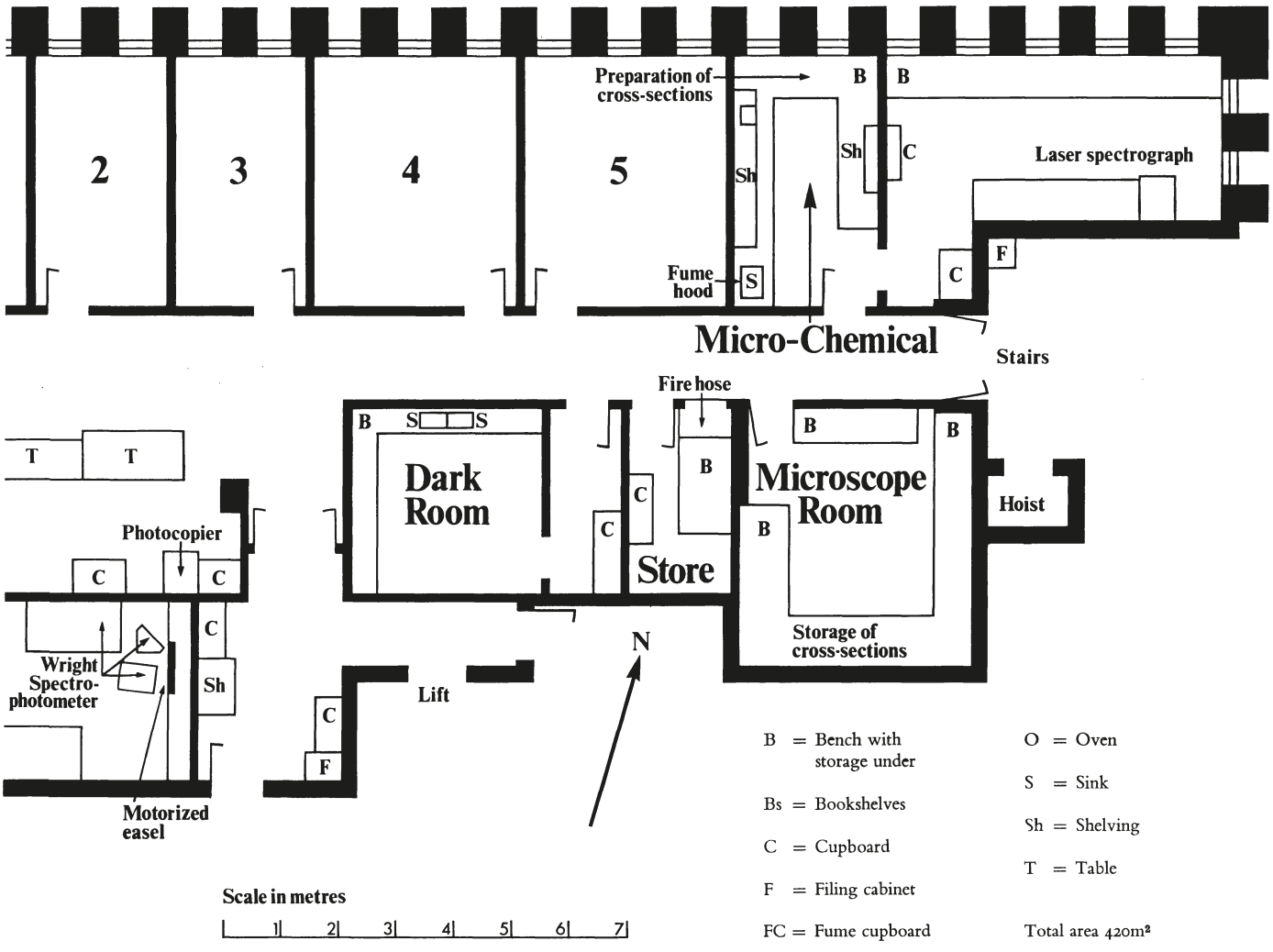
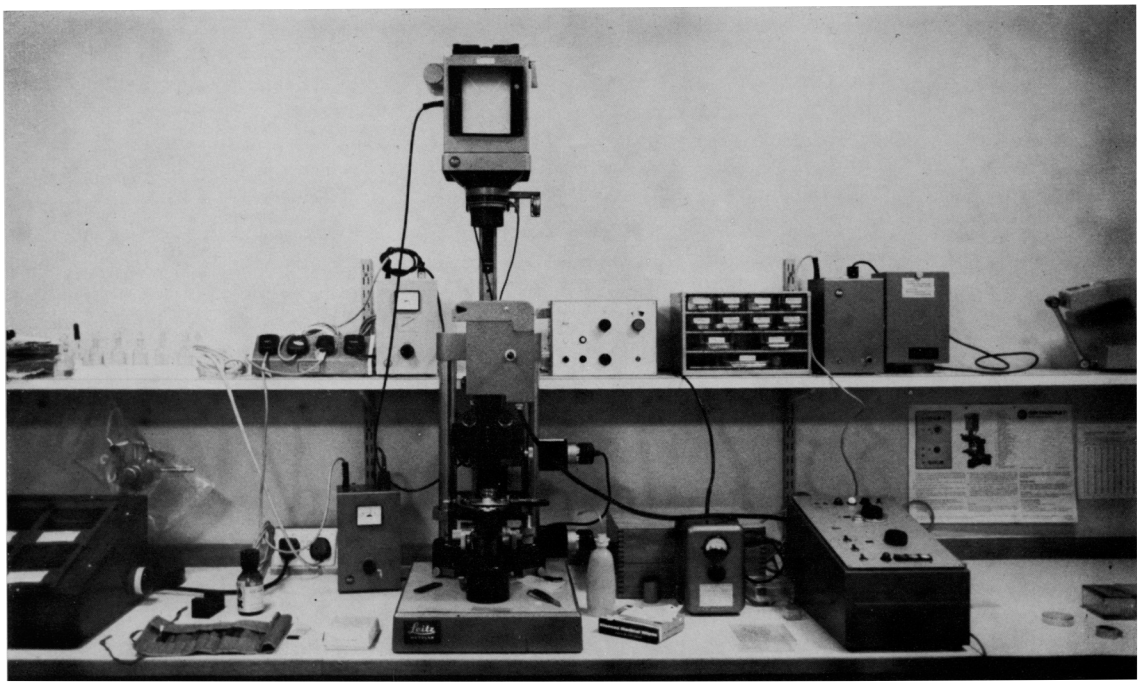


Figure 2. Plan of the Scientific Department. Windows at regular intervals, glazed with grey glass, side-light the north and west of the laboratory. There is no top light, but clerestory windows in the inside walls of the offices allow daylight to reach the centre of the laboratory. Air-conditioning is to 55% RH, 21°C. BCF fire extinguishers and blankets are provided at several points, a fire-hose can reach all areas, and ionisation smoke detectors are fitted in all rooms. Inflammable solvents are stored outside the building. Earth-leakage circuit-breakers are fitted on all ring mains. Office and library areas are carpeted.

The height of the bench on which it stands (76 cm) is less than that of the standard laboratory bench in order that the operator may sit comfortably at the microscope, feet firmly on the floor. Microscope and camera accessories are in drawers and cupboards within arm's reach. A narrow shelf attached to the wall above the main microscope bench is provided for boxes of electrical controls and other much-used accessories. The 'Orthoux' microscope has built-in transmitted and incident light sources, separately adjustable as well as capable of being used together (often a help in studying paint and pigment samples). For incident light, the Leitz 'Ultropak' illuminator and objectives were chosen. In this system a hollow cone of light is directed from around the objective lens onto the sample. The resultant illumination shows up the structure of semi-opaque materials like paints and pigments far better than the vertical illumination customarily used for metal specimens. On the 'Orthomat' polarizing facilities have been restricted deliberately to a slide-in analyser and a rotating, but not graduated, polarizer, sufficient for detection of birefringence. A fully-equipped polarizing microscope is also available in the Department (see below and Fig.5). Photomicrographic equipment was soon added, first the 'Orthomat' 35 mm automatic camera then a large-format (12.5 × 10 cm sheet film or plate) bellows camera, also with automatic control. Although high quality photomicrographs can be obtained using an ordinary reflex camera on top of the microscope, the process is rather time- and film-consuming, particularly with colour work. The 35 mm camera is particularly useful for rapidly recording series of samples and for photography of transient phenomena like chemical reactions, the sample being under continuous observation while the photograph is taken. Both cameras have two types of exposure reading, one giving an average reading for the whole field, the other a reading on a small selected area, the latter indispensible for small samples in the centre of a dark or bright field. A tungsten-halogen lamp can be inserted in a separate lamp-housing to replace or supplement the built-in tungsten lamp for incident-light study of dark specimens or for accurate focusing of the image on the ground-glass screen of the large-format camera. This lamp is interchangeable with a high-pressure mercury vapour lamp to provide illumination in the blue and ultra-violet range for fluorescence microscopy. Although a few pigments fluoresce in UV, it is the paint media and varnishes which more commonly exhibit fluorescence. Such organic materials cannot be specifically identified by their fluorescence in UV, but they exhibit different types and degrees of fluorescence depending not only on differences in their chemical composition initially, but also on differences in age and degree of chemical degradation of the same material. It is often possible to distinguish by this means layers of old varnish between original

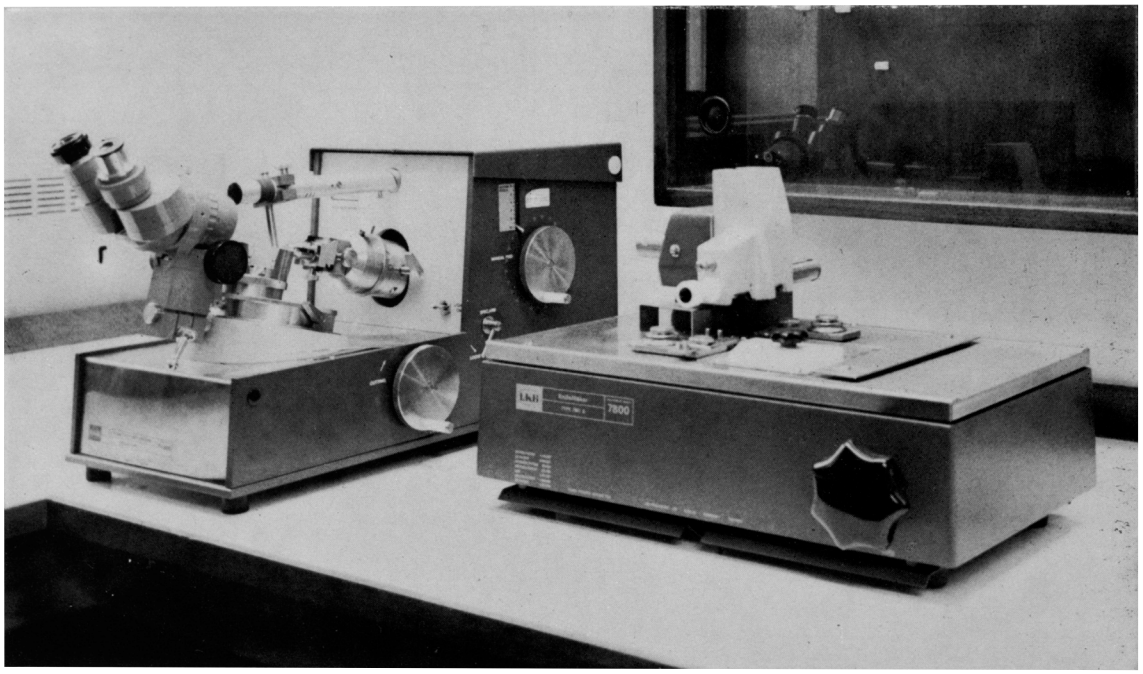




paint and repaint, or to discriminate between two paint layers in a cross-section which look identical under visible light and which may even have identical pigment but different media. The method is a help, like staining tests for media (see p.56), in establishing whether more than one sort of medium is present before embarking on instrumental methods for media analysis, such as gas or thin-layer chromatography. In fact it might here be stressed that optical microscopy is a useful and often necessary preliminary to the further examination or analysis of samples by any other method. For dissecting samples under the microscope prior to separate treatment of the various layers and components, there is a pair of Singer micromanipulators. Unlike the more usual type of micromanipulator which moves along coordinates, this type simply scales down the natural movements of the hand by a factor of four (in the case of our particular model) and enables small tools to be used under the microscope in the manner of a knife and fork to manipulate or dissect the sample.

The *Microchemical Laboratory*, for want of a more apt name, is a long narrow room with benches on three sides. One long bench, with a small sink and fume-hood at one end, serves for chemical microscopy, spot tests and other small-scale chemical reactions. A comprehensive range of chemical reagents, particularly organic reagents used in spot tests, is in glass-fronted cupboards above the bench. The rest of the bench space in this room is used for preparation of cross-sections of samples. The more frequently-prepared type of cross-section, i.e. the thick, opaque sections for viewing by incident light as described above, is ground and polished on a 'Metaserv' low-speed polishing wheel with interchangeable heads for the various grades of abrasives used. Thin sections for viewing by transmitted light may be cut from even smaller paint samples using the LKB 'Pyramitome' glass knife microtome (Fig.4). Old paint is not the ideal subject for thin-section microtomy for it often contains large particles of hard minerals, such as haematite, likely to damage any knife blade. Steel microtome knives are expensive to resharpen and the cost of a diamond knife of adequate cutting width would be prohibitive. Hence the choice of a glass-knife microtome. The triangular-shaped knives are literally pieces of broken glass. Nowadays, instead of being made by breaking glass with two pairs of pliers, they are rapidly and inexpensively made from strips of plate glass with a special knife-making machine (Fig.4) which gives a choice of angle for the cutting edge and exactly reproducible knives. The paint flake to be sectioned is embedded in a synthetic resin as before (though an epoxy resin is usually preferred to the polyester used for thick sections). The trimmed block of resin is placed in the sample holder and thin serial sections are cut, knife blade and sample simultaneously observed through a binocular magnifier. If one knife-blade is seen to be damaged another of three on a rotating mount can be moved into place. The thickness of the sections to be cut can be chosen between 1–10μ. Even at this degree of thinness paint layers containing lead white and similarly dense pigments are opaque by transmitted light when viewed under the microscope. The principal use for these thin sections is the study of glaze layers containing relatively transparent pigments such as lakes of organic dyestuffs. There are also advantages in using thin sections rather than thick opaque ones in staining tests for media (see p.56). A programme of work on the identification of lake pigments of organic dyestuffs and of other glazing pigments using thin sections is being carried out on a Leitz comparison microscope equipped with a photomultiplier and variable-wavelength interference filter (see pp.35-44).

The polarizing micropscope mentioned above (Fig.5) is housed in the *Laser Room* adjacent to the Microchemical Laboratory, which enables it to be used when the Microscope Room is occupied. A Leitz 'Ortholux-Pol', it is fully-equipped with rotatable analyser having scale and vernier reading, polarizing condenser, rotating graduated stage, Bertrand lens for conoscopic observations and compensating plates. There is built-in trans-



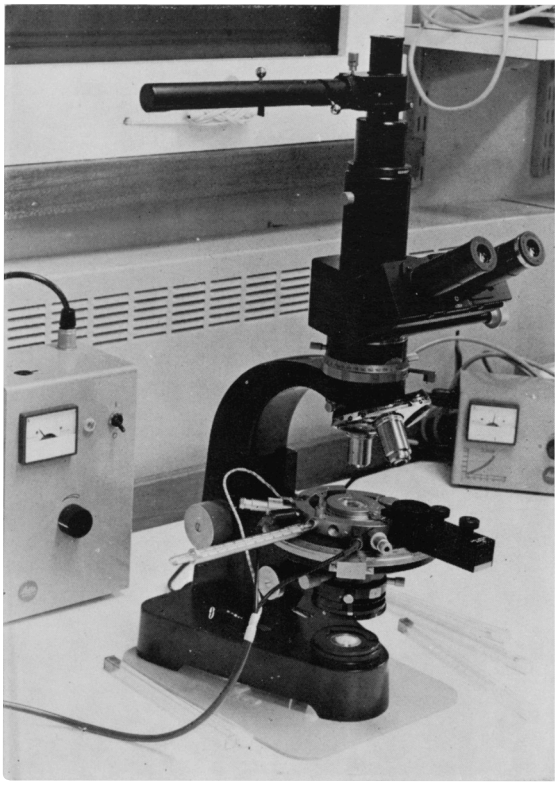


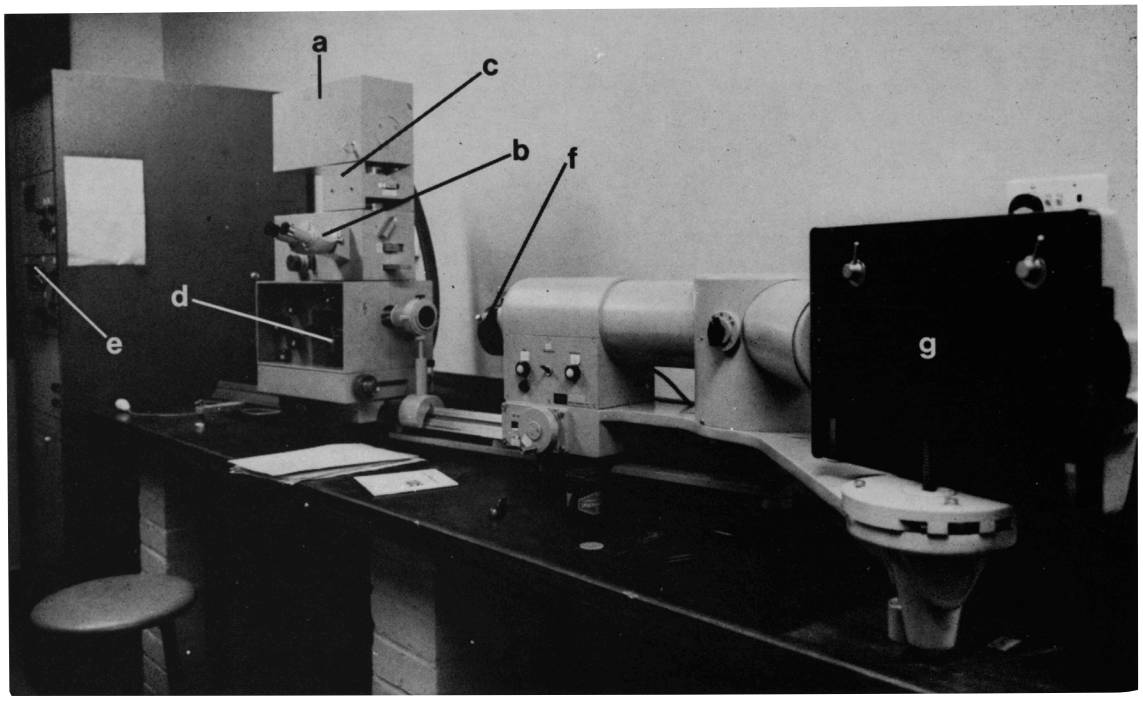
Figure 3 (*Top left*). The Microscope Room, detail of microscope bench. The Leitz Ortholux microscope occupies the central position. Connected to the phototube at the top is the 35mm. Orthomat camera, its control box on the bench far right. The large-format camera, with ground glass screen for focusing the image, has been slid up the vertical support out of the way, its control box being on the shelf adjacent.

Figure 4 (*Top right*). The LKB Pyramitome glass-knife microtome and LKB Knifemaker. The knife edge and the sample being cut can be kept under observation through the binocular magnifier. The triangular-shaped glass knives are made from rectangular strips of plate glass on the knife-making machine on the right.

Figure 5 (*Above*). The Leitz Ortholux-Pol polarizing microscope. The heating stage has been superimposed on the normal graduated rotating stage. A special eyepiece inserted in the phototube of the microscope enables the sample being heated and the thermometer cale to be observed at the same time.

mitted light with interchangeable tungsten or sodium lamps. The polarizing microscope is used for examinations at higher magnifications by transmitted light, for measurement under the microscope and for determination of optical properties such as refractive indices and birefringence. A recently-acquired accessory is a heating stage (Fig.5) which may be rapidly and easily attached to the rotating stage. The sample is placed between a heat-proof glass slide and cover slip in a central heating chamber and can be heated at a controlled rate to 350°C. An eyepiece attachment enables sample and thermometer scale to be observed at the same time. Applications have been in the study of effect of heat on pigments and media (the presence of waxes, for example, is readily detected) and accurate determination of the melting point of organic compounds. It is hoped to carry out tests on a series of lining adhesives in conjunction with the Conservation Department.

The *Laser Room* takes its name from its principal occupant, a Zeiss (DDR) Laser Microspectral Analyser (Fig.6). The apparatus is ranged along one side of the room on a slate bench supported by brick piers. When first acquired it was laid out on sturdy wooden benches but each time a change of relative humidity occurred in the atmosphere the wood moved and the very long light path had to be painstakingly realigned. A touch of tradition is that the slate for the bench top was salvaged from the floor of one of the old galleries! The central feature of the apparatus is a binocular microscope above which is situated the laser head containing a neodymium (Nd^{3+}) glass laser resonator (laser wavelength 1060nm) and flash tube. The laser head is connected to the microscope by an optical adaptor with variable diaphragm. The sample to be analysed is placed on the microscope stage. It can be of any shape or size which can be accommodated on the stage and requires no previous preparation. The surface of the sample is focused under the microscope and the intersection of the eyepiece cross-wires centred on the exact spot to be analysed. The laser beam strikes the sample at this spot and in doing so



vaporizes a minute quantity of it leaving a small crater in the surface. The diameter and depth of the crater may be controlled by varying the capacitance and inductance values and the flash lamp voltage at the supply unit and additionally by means of the optical adaptor. Situated between the microscope objective and the sample surface is a pair of carbon electrodes. When the laser beam strikes the sample a minute cloud of vapour is formed between the electrodes and causes them to discharge (the voltage having been preset to just below that for discharge). The light produced, the wavelengths of which characterize the chemical elements present in the sample, is directed into the slit of a conventional prism spectrograph, in our case the Zeiss Q24 UV Spectrograph and the spectrum produced recorded on a photographic plate. By a happy coincidence the range of diameter of crater produced, approximately 10–100μ, is about the same as the range of thickness of the layers found in cross-sections of samples from pictures. This makes it possible to analyse paint sections layer by layer or even to analyse single large pigment particles. By modifying operating conditions it is also possible to choose whether to analyse for principal constituents only or for minor impurities as well. The laser microspectral analyser was chosen in preference to the more usual type of emission spectrograph (in which the sample is inserted into one of the electrodes and is destroyed in the process of analysis) because we wanted to do further analysis on many of our large and irreplaceable collection of paint cross-sections from pictures without destroying their value for optical microscopy. The slight damage to the surface of the section caused by the laser beam can be removed by a little further polishing if required, but a neatly-formed crater is sometimes a useful record of the exact site of analysis. The equipment is completed by a spectrum projector for reading the resultant spectrographic plates. At present the instrument is used for qualitative and semi-quantitative analyses. Certain difficulties arise with quantitative analysis as compared with conventional emission spectrography. It is doubtful, however, to what extent quantitative analysis is applicable to the heterogeneous mixtures so often found in paint samples from old pictures and it is a problem we have not yet tackled. It should be pointed out that laser microspectrochemical analysis, like many other methods of analysis, indicates only the chemical *elements* present in the sample. To interpret these results in terms of chemical compounds or actual pigments present the method needs to be used in conjunction with optical and chemical microscopy and/or X-ray diffraction.

Organic analysis

Museum objects, including paintings, incorporate in their compositions a wide range of natural organic materials. First there are the materials such as wood, animal and vegetable fibres, and skin products such as leather and parchment, which can play a major structural role. Then there are the minor (in terms of bulk) components such as drying oils, waxes, plant gums, proteins such as albumin and gelatin, and the natural plant resins, which are present as adhesives, varnishes, or binding media for paint. Distinguishing between materials of the first group can usually be done by simple inspection, while determination of generic or species origins, of woods say, normally involves following well-defined routines in microscopy rather than any kind of chemical analysis.

With the minor components, however, it is not normally possible to tell from simple inspection what class of material is involved, and indeed the material may not even, as with paint media, be visible for inspection in any real sense. Relatively simple tests of solubility or chemical properties will quite often serve to answer this first question, though not if mixtures are involved or properties are disguised by the presence of large amounts of inorganic materials. In the latter cases,

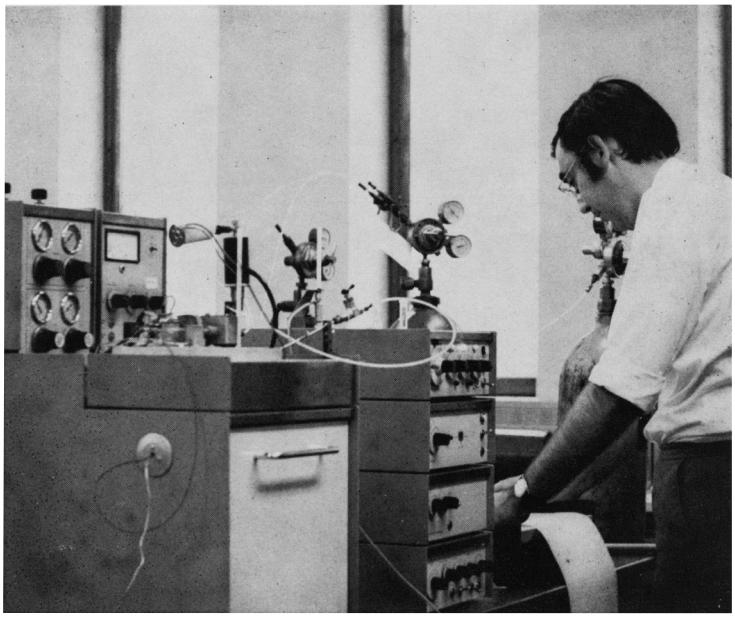


Figure 6 (*Top left*). The Zeiss Laser Microspectral Analyser. The laser head **(a)** is connected to a binocular microscope **(b)** by means of an optical adapter **(c)**. The sample is placed on the microscope stage **(d)** and enclosed by glass doors which lock with a safety device when the laser and electrodes are operative. The pair of carbon electrodes is situated just above the microscope stage. At the far left **(e)** is the power unit and control panels for laser and electrodes. Light emitted by the simultaneous firing of the laser beam at the sample and the discharge of the carbon electrodes is passed through a condenser into the slit (slit head **(f)**) of a Zeiss Q24 medium quartz prism spectrograph where it is split up into its component wave lengths and the latter recorded on a photographic plate in the plate-holder **(g)**.

Figure 7 (*Top*). A view of part of the general chemistry laboratory. The two peninsular benches are designed for wet-chemical operations such as work-up of samples and some analytical procedures. Two fume-cupboards are at the ends of the benches. In the same laboratory (not seen) are two island benches used for gas-chromatography and spectrometric apparatus, while further benches and cupboards range around the walls.

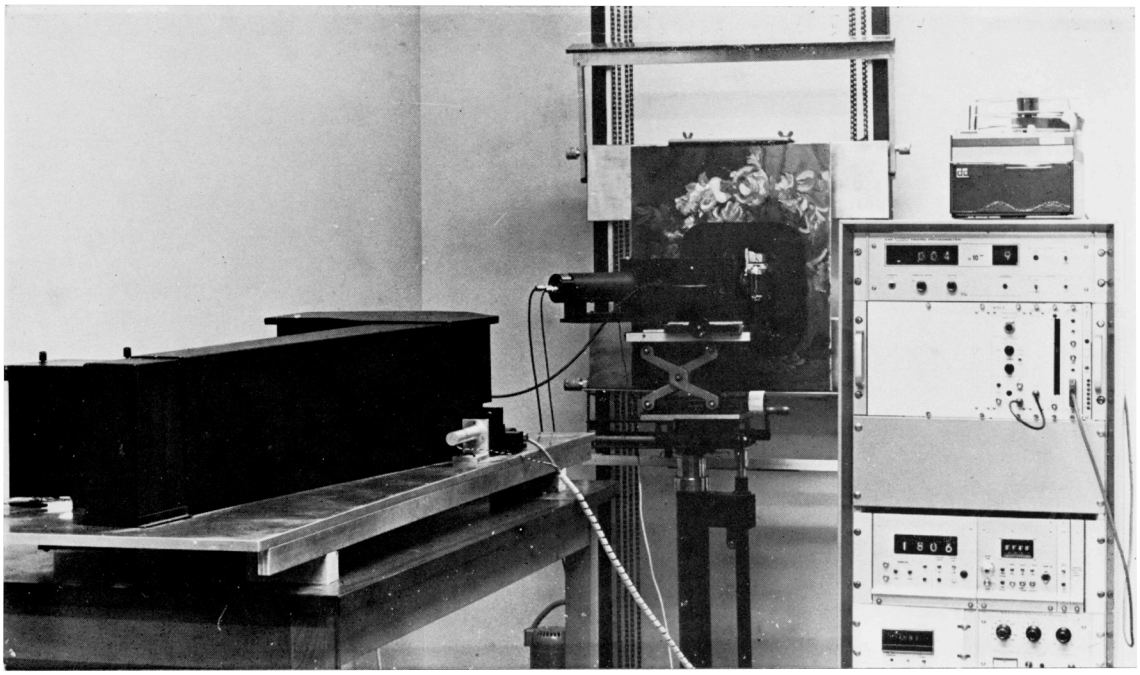
Figure 8. The gas-chromatography equipment. Principally used for the determination of paint media by fatty-acid analysis, the method is also applied to the identification of proteins, waxes, and natural resins.

and when more specific identification is wanted it is necessary to resort to fairly sophisticated chemical and instrumental techniques and ones, moreover, which are capable of giving results with very small samples.

There are essentially no methods of organic analysis applicable to these materials which can be used on the object itself; it is always necessary to remove a sample for study. Furthermore most of the methods will also involve the destruction of this removed sample by dissolving it to separate organic and inorganic components, or to get it into suitable form for the method to be used. Obviously this is a drawback when structured samples, such as those from paintings, are involved. Some tests on cross-sections of such samples can be effected by biochemical staining in favourable cases, but this is more the concern of the microscopist. To get really meaningful results from the following instrumental methods therefore, samples which are as homogeneous as possible are desirable.

The two main areas of analysis for which the Department is equipped are those involving spectrometric methods and the various forms of chromatography. Ultra-violet and visible spectrometry is only rather rarely useful. Few organic materials encountered in old objects retain distinctive ultra-violet spectra that they may originally have had. This is for a very good reason, namely that the possession of such absorption renders the compounds naturally susceptible to photochemical reactions and hence change. With coloured compounds the possession of a visible absorption spectrum is an inevitable attribute and measurement of this is a valuable aid to identification with organic dyestuffs that can be separated from the substrate and brought into solution in sufficient quantity. This is only rarely possible with samples from paintings which is why the direct measurement of such spectra on thin sections, described elsewhere in this bulletin, has been investigated. Infra-red spectrometry is a basic technique for identification of organic materials but again one which is only rarely useful for samples from paintings. It comes into its own with samples which are not too complex mixtures of disparate chemical types in the first place, and which are not too liable to chemical change with time, and waxes are a good example of such material. Even with these, however, more convincing analyses (especially with mixtures) on smaller samples are obtainable using gas-chromatography.

Gas-chromatography is the most valuable and generally applicable of the chromatographic techniques, and indeed of all the methods available to us. The Scientific Department obtained its first gas-chromatograph (a Pye 'Panchromatograph') in 1962 before anything was known of its usefulness in this field and consequently with some misgivings as to whether it would prove a good investment. Already by the following year its value for paint medium analysis was established and it has been used almost routinely for this since then. A much superior Pye 104 instrument has been in use since 1970 (Fig.8). As mentioned above gas-chromatography is also used for the identification of waxes and indeed for most of the groups of natural materials which have been mentioned. Thus proteins are identified by GLC of derivatives of their constituent



amino acids, and the natural resins can also be characterized after suitable derivitisation of their component di- and triterpenes. Resins containing triterpenes (such as dammar and mastic) are a particular challenge because of the high molecular weight (and hence boiling point) of their components. A system of capillary column chromatography of the trimethylsilyl derivatives has been developed for these.

Gas-chromatography identifies natural materials by separating them into their components. The pattern of peaks which results may sometimes be used simply as a characteristic of the material but more often, and more informatively, the chemical identities of the compounds responsible for each peak are ascertained by comparison with known samples and their amounts estimated from the peak sizes. Thus information may be acquired, not only regarding the nature of the raw materials, but also the ways in which they change with time. Some materials change very much with time and produce many new unidentifiable peaks on the chromatograms. It would be most desirable to be able to have fuller information on these and this could, of course, be obtained with the now well developed methods of combined gas-chromatography/mass-spectrometry linked with a computer data-processing unit. The relatively high cost of such an installation has so far prevented our acquiring it.

Research on the effects of the environment

The effects of those factors in the environment which cause deterioration—light, air and its impurities, humidity, heat, etc.—can often be ascertained in laboratory conditions of accelerated exposure. One then extrapolates these results with somewhat reduced confidence to the real-life conditions of exhibition.

At the present time the laboratory has chosen to concentrate on the longer-term procedure of measuring the actual changes that occur on the paintings in the collection. Since these changes are very slow, the measurements must be as sensitive as possible to yield results as soon as possible.

Apart from physical destruction of the paint surface, the most significant change that needs study on paintings is colour-change. We have therefore chosen as our first objective the organisation of regular colour measurements on paintings in the collection.

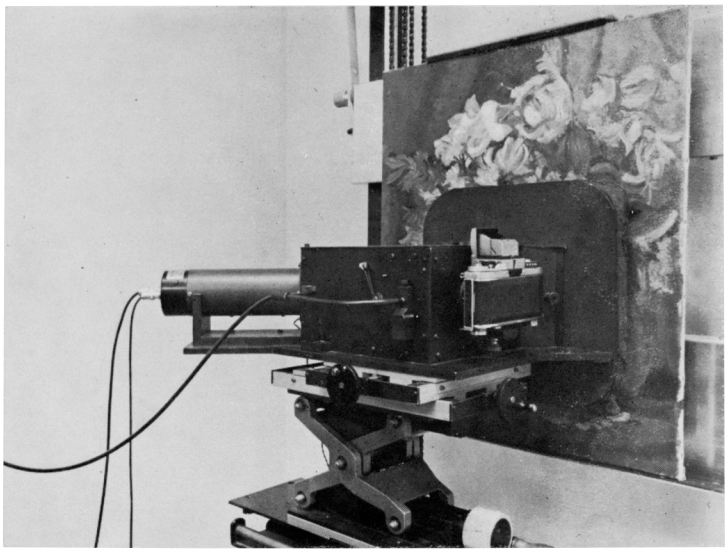
The colour of a reflecting surface can be recorded in two ways, by colorimetry or by spectrophotometry. The first, colorimetry, involves measuring reflectance of an area of colour at at least three wavelengths. By a standard mathematical procedure this allows us to record the colour as three coordinates on a three-dimensional diagram. Any change in colour will result in a change in one or more of these coordinates.

The more detailed procedure that we have adopted, reflectance spectrophotometry, records the complete visible spectrum from 380 nm to 760 nm and gives us more information on the nature of any colour change, even allowing identification of the pigment used in certain cases.

The first step was to acquire suitable instrumentation. Apart from the inaccessibility for a painting of the sample chamber in a commercial reflectance spectrophotometer, previous work had shown that large inaccuracies are involved in attempting to come back to the same position on a painting for a second measurement at a later date.

We had the great good fortune at this stage of enlisting the help of Professor David Wright, then Professor of Applied Optics at Imperial College and a noted international figure in the development of colorimetry. With the help of a grant from the Paul Instrument Fund, Professor Wright together with Dr. Wassall built a reflectance spectrometer of the type and accuracy required (Figs.9,10).

This instrument is now at work in the Scientific Department. The procedure is that a small but expanding group of paintings, generally having just undergone restoration and therefore not likely to be treated in any



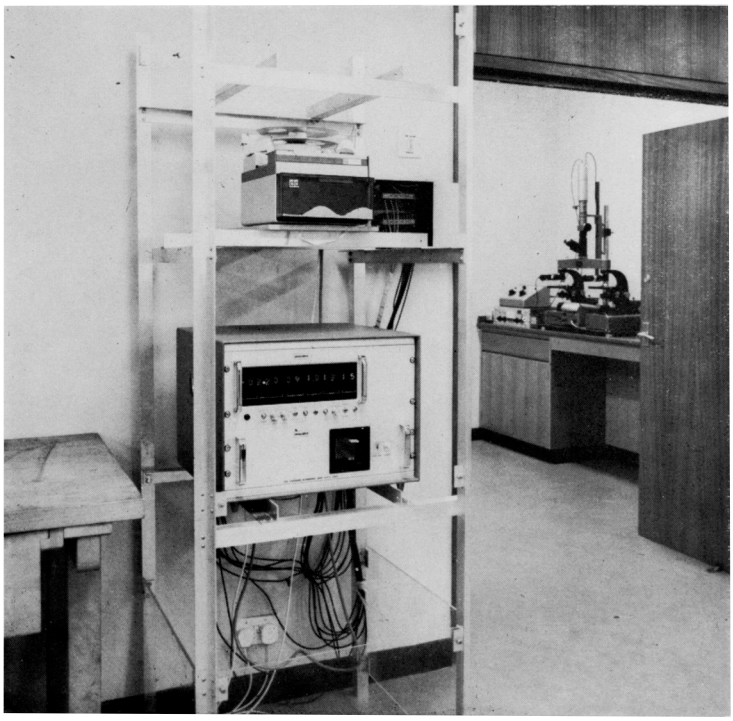


Figure 9 (*Top left*). The Wright-Wassall reflectance spectrophotometer. The black box on the left houses the light-source and monochromator from which light of the selected wavelength passes along a fibre-optics light guide to the measuring head (Fig.10). The easel holding the painting is motorized for remote control of horizontal and vertical movement (J. Money). On the right is a bank of electronics which receives signals from the measuring head, processes them and transfers them to punched tape.

Figure 10 (*Top*). The measuring head on its stand for fine adjustment in three dimensions. Light of the selected wavelength enters the head through the light guide coming in left. It is imaged on the paint surface as a 4mm diameter circle. Light reflected at 45° is collected by the photomultiplier on the left of the head, which sends its signals to the bank of electronics in Fig.9. The measuring head contains an internal standard and a 35mm camera for recording the point of measurement. No part of the apparatus touches the paint surface.

Figure 11. Datalogger (Mycalex) with tape punch above (Data Dynamics). At present the logger receives 20 channels of information from temperature, RH and illuminance sensors in the Northern Extension. Every hour the logger punches date, time and the voltage inputs from the 20 channels. Through the door on the right can be seen the Leitz comparison microscope with microdensitometer and interference-filter monochromator (p.39).

way for many years, will each have measurements made at five-year intervals on about half a dozen areas of about 4 mm in diameter. These areas are chosen, obviously, for susceptibility to change as far as our knowledge goes, and to them are added supposedly stable areas as checks and measurements of varnish yellowing. Results are recorded in the form of reflectance readings at 10nm intervals, and include a macrophotograph taken by the measuring head of each area of measurement. With this device one can return to the same point of measurement without significantly disturbing accuracy.

Any information on colour change is important for such valuable objects as the paintings in the National Gallery collection, but it becomes the more important the more it can be linked to the factors in the environment causing the changes. The most we can do at the present is to ensure that our record includes what we now consider to be the necessary data on the environment. Thus we need a continuous record of illuminance, humidity and temperature. This cannot be done for every painting, but the record should allow a reasonable estimate to be made for each painting under measurement. We should also acquire knowledge, which need not involve a continuous record, of the proportion of UV in the light, and of pollutants such as sulphur dioxide and ozone in the room air, with seasonal variation and drift.

The main instrument selected for this purpose is a data logger which reads from sensors planted in the Gallery exhibition rooms or ducts in the air-conditioning system (Fig.11). Our data logger is now in the pilot stage, taking hourly records, but only from the ten rooms of the new northern extension to the Gallery, of illuminance, RH and temperature. These go onto punched paper tape, which is computer-tabulated and processed.

Computing

The recent phenomenal progress in computing facilities has been reflected on a small scale in the Department's change from hand-operated calculator in the '50s through electromechanical and programmable desk-calculator to the present Wang system with 16K capacity (Fig.12).

Top-of-the-range calculators such as the Wang overlap the minicomputer in price and capacity, the minicomputer having advantages in speed of operation for long routine calculations and in link-up with instruments, and the Wang in mathematical work and ease of programming.

The system in use at present comprises a 16K central processing unit with CRT display, storage on disc and magnetic-tape cassette, a punched-tape reader and an IBM plotter/writer for hard copy. Its instructions are in Basic. Its ease of programming, with sixteen lines of programme or output displayed on the screen at one time, has made it possible for the staff of the laboratory to write their own programmes without the need to attend any training course.

Some of the uses made of the Wang system are as follows:

Each week the punched-tape output voltages from

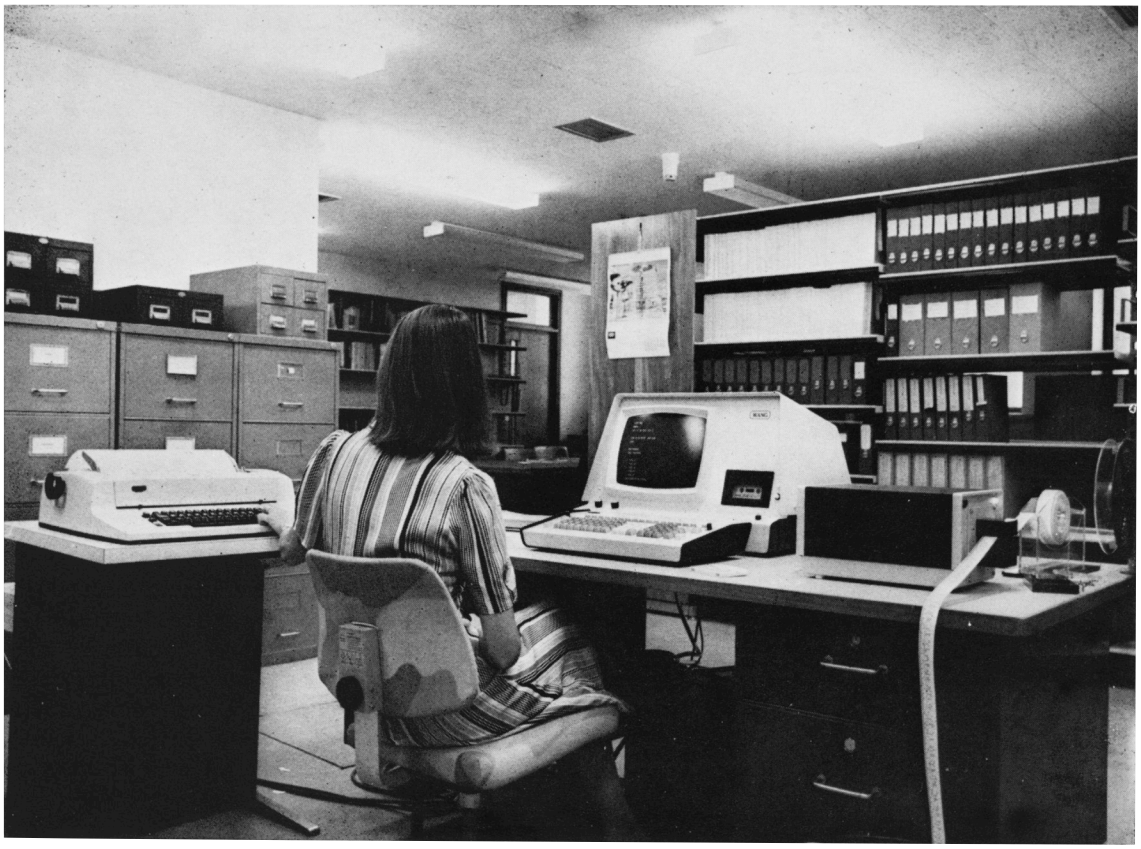


Figure 12. The Wang 2200 calculating system. The central processor has a capacity of 16K bytes and incorporates a screen for the display of programme and data. Storage is on magnetic-tape cassettes. The writer on the left is capable of plotting graphs through movement of the printing position in increments of 1/100th inch. On the right is a paper-tape reader.

the data logger are read, converted to illuminance, relative humidity and temperature and printed out as a table. A programme for drawing attention to malfunctions is also used, and the data can, of course, be manipulated as required.

Colour-rendering calculations of fluorescent lamps and other illuminants, which took half a day with the electromechanical calculator, can now be carried out in five minutes. Formerly the time needed to acquire such information was often not available.

The Wright-Wassall spectrophotometer being a single-beam instrument, each wavelength reading must be referred to an internal standard, which in turn is referred to a ceramic-tile standard. In practice groups of readings are outputted to punched tape. Averaging and all subsequent computations of reflectance readings are carried out by the Wang.

The Wang is also used to integrate gas-chromatograph peaks for quantitative work. When fed with retention times from capillary-column gas chromatographs it will deal with variations caused by column ageing and identify peaks from a store of data on known compounds.

Lastly we are starting to put chemical data and other reference material onto magnetic tape, but find inevitably that we shall have to increase our storage capacity.

Several other programmes have been developed for use in current research, but the reader will note that two items in the above list depend on the Wang. The data logger has the great advantage that it can accept voltages from any type of sensor, but its punched-tape output can only be machine-read, and the Wright-Wassall spectrophotometer would be a very slow instrument without computing backup.

Availability of analytical results

Many of the analytical results continually being produced by the Scientific Department amount to single elements in a many-sided technical examination. Collected by themselves they become items in a list, and as such are not always suitable for publication in the rounded articles which appear in most journals. This means that, unless each technical examination itself is made widely available, the analytical results are accessible only to a narrow circle. However, as they accumulate they increase very greatly in value.

This is one of the reasons why the Trustees of the National Gallery have arranged for the publication of an annual Bulletin on the technical work at the Gallery. The first set of such results are to be found on pp.57–59 of this issue.