Mariner IV: Developing the Scientific Experiment

Attention to detail and continuous tests at all stages were responsible for the success of the mission.

Glenn A. Reiff

During the 2½ months after its encounter with Mars, Mariner IV sampled the interplanetary environment to a distance of about 1.57 astronomical units from the Sun and continued to function well.

On 1 October 1965, the receipt of interplanetary scientific data from the spacecraft was discontinued. On that date—the 307th day of a flight roughly equivalent to 1600 trips to the Moon—a command to shift its radio transmissions from the directional to the omnidirectional antenna was sent from Earth and was acknowledged by the spacecraft some 33 minutes later.

Mariner IV's compliance with this command marked the end of the 1964–65 Mariner mission, and therefore it seems timely to recount some of the experiences associated with the development of the scientific payload for the flight.

The Mariner spacecraft missions and preliminary results of investigations made in the region of Mars have already been described (*1*). In this article I will summarize the steps taken to combine the scientific instruments with the other vital elements of the spacecraft to create a spaceworthy craft capable of a reliable 10-month mission.

Project Definition

Toward the end of 1962, the National Aeronautics and Space Administration, on the basis of studies completed at the Jet Propulsion Laboratory, approved the Mariner Mars '64 Project for the development of spacecraft to be launched toward Mars by the Atlas-Agena vehicles.

It was necessary to decide upon a conservative set of scientific objectives for the mission and to implement these with a maximum of equipment redundancy and alternate modes of operation. Probably the most significant goal of the design was the development of an "automatic spacecraft"—a spacecraft able to complete its entire mission from launch to end of life without ground-based intervention except for the midcourse guidance maneuvers and, of course, tracking and data acquisition. Another design objective was to have at least two independent means of initiating every discrete function or event critical to the success of the mission (*2*).

Since these spacecraft, which later became known as Mariners III and IV, could weigh no more than about 260 kilograms, and since the development had to be completed in less than 2 years, NASA headquarters decided to select the scientific instruments from the group chosen earlier as scientifically well suited for the initial flight to Mars. Concurrently, several activities which would be fundamental to the project were set in motion by the project manager at the Jet Propulsion Laboratory (*3*). These included completing the preliminary system design; ordering long-lead-time parts; establishing the launch period; evolving the Project Policy and Requirements Document; and formulation of the Project Development Plan.

While narrowing the field of possible instruments for the mission made the task of selection easier, difficult choices still had to be made. An infrared spectrometer had to be rejected because it was too heavy and its weight could not be reduced in time, a television camera had to be scaled down and fewer pictures could be taken, only one plasma detector could be included, and so on.

A complement of eight scientific instruments was approved in March 1963, but subsequent developmental problems required the removal of one. Those flown on Mariner IV are listed in Table 1. Except for the television and the magnetometer, models of these instruments with different capabilities had been flown in space before. In early 1964 a novel and scientifically important experiment which required no additional spacecraft equipment was conceived and proposed. As a result, the occultation investigation for measuring the density of the atmosphere and ionosphere of Mars was approved, and the encounter plan was modified to accommodate it.

Spacecraft Integration

Once the instruments had been selected, various spacecraft design activities could proceed. One task was to adapt either the instruments or the spacecraft design to insure mutual compatibility and to settle upon a spacecraft configuration. Engineering models of the instruments, as well as of other assemblies, were built, and testing was begun.

Because of weight limitations, extreme communication distances, and the requirement for long life, the scientific instruments had to be very closely integrated with the other elements of the spacecraft and developed under stringent quality-assurance controls.

Deciding upon the final configuration for the spacecraft was an iterative process in which compromises had to be made among the requirements for fulfillment of the objectives of the experimenters, the communicators, the structural designers, the guidance and control engineers, the launch-vehicle specialists, the electrical power-system designers, and the data-handling engineers (*4*). A typical trade-off stemmed from the need of the solar-plasma experiment for a 15-degree unobstructed view of the Sun. However, the instrument could be allowed to point a small angle away from the direct Sun line without significant compromise to the data. Thus it could be located on the primary structure, and the total design was simplified. An-

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Table 1. Scientific instruments on Mariner IV.

Instrument	Purpose
Magnetometer	To measure magnitude and other characteristics of the planetary and interplanetary magnetic fields
Ion chamber	To measure charged-particle intensity and distribution in interplanetary space and in the vicinity of the planet
Trapped-radiation detector	To measure intensity and direction of low-energy particles
Cosmic-ray telescope	To measure direction and energy spectrum of protons and alpha particles
Plasma probe	To measure the very-low-energy charged-particle flux from the Sun
Cosmic-dust detector	To measure momentum, distribution, density, and direction of cosmic dust
Television subsystem	To obtain closeup pictures of the planet surface

other example is that a spacecraft magnetic background higher than desired had to be accepted by the magnetometer experimenters because the requirements for reliability of the mission were overriding.

In the final design, 11 percent of the total weight of the spacecraft could be allocated to the scientific subsystem, yet this subsystem contained about 50 percent of the 32,000 electronic components used in each spacecraft.

The broad plan for development of the spacecraft and a system of controls were established by the Project Policy and Requirements Document. This document described the amount of equipment to be built, assembled, and tested; configuration control; quality control; parts control; test requirements; key planning and control documents required; procurement requirements; organization; and schedule control. The reliability and quality-assurance requirements generally followed those recommended in NASA Handbooks NPC 200-2 and NPC 200-3. Table 2 outlines the various kinds of equipment and the types of tests conducted on each. To implement the testing plan at least six units of each instrument were needed—an engineering model, a type-approval unit, a flight-acceptable unit for the proof-test spacecraft, and three flight units. The phasing of the various tests, as well as that of some of the activities already described, is shown in Fig. 1.

The initial goal was to use only those parts and materials that had received space certification and were listed as "Hi-Rel" parts; however, the requirements of the mission and the designers soon led to exceptions to this objective. Because of these exceptions and the operating lifetime required to complete the mission, it was decided to screen all electronic and electromechanical parts used in the qualification test, flight, and spare spacecraft (*5*). A few waivers to this requirement were granted in October 1963 because of schedule slippages. Nevertheless, during the course of the project some 350,000 parts, including over 90 percent of the parts on each Mariner, were screened. A typical process, depicted in Fig. 2, involved burn-in and parameter-drift measurements.

The original design of the radio subsystem employed redundant S-band planar triodes for the final power output stage. One reason for the initial selection of this type of amplifier was that it could be made to have a lower external magnetic field than other types of radio-frequency power amplifiers and would, therefore, aid in keeping the background magnetic fields of the spacecraft low. By late 1963, life tests conducted in conjunction with the parts-control program indicated that these tubes might not be able to operate continuously for 6000 hours. As a result, in early 1964 a major redesign of the radio subsystem was undertaken to substitute a traveling-wave tube for one of the planar triodes. The use of two kinds of power amplifiers in the radio transmitter provided a unique type of redundancy.

By means of design-verification tests, the engineers were able to prepare final specifications and to establish performance margins. For the production of qualification-test and flight assemblies, quality-assurance instructions were written and in-process flow plans showing inspection points were approved. In-process inspection was an important means of controlling and measuring the quality of the Mariner hardware. Generally, some 1500 inspection points at subcontractor plants during the in-process phase of manufacture plus 256 final inspection points were established.

Circuit designers and other specialists conducted failure-mode and worst-case analyses of each assembly while it was being built.

Another series of tests provided a means of integrating the various instruments or assemblies into subsystems and then into a functioning spacecraft. The parts and functions tested included mechanical assembly, grounding of the test complex of the spacecraft system, initial power application, subsystem interaction, mission profile, parameter variation and power profile, telemetry calibration, and magnetic

Table 2. Equipment-test matrix

Equipment category	Test purpose: Space certification	Screening	Design, verification, and fabrication	Integration	Flight acceptance	Type approval (qualification)	Life	Prelaunch checks	Mission support
Parts and materials	X	X					X		
Sub-assemblies (Circuits and mechanical components)			X				X		
Assemblies (including scientific instruments)			X	X	X	X	X		X
Subsystems			X	X					
Proof spacecraft						X			X
Flight spacecraft					X			X	

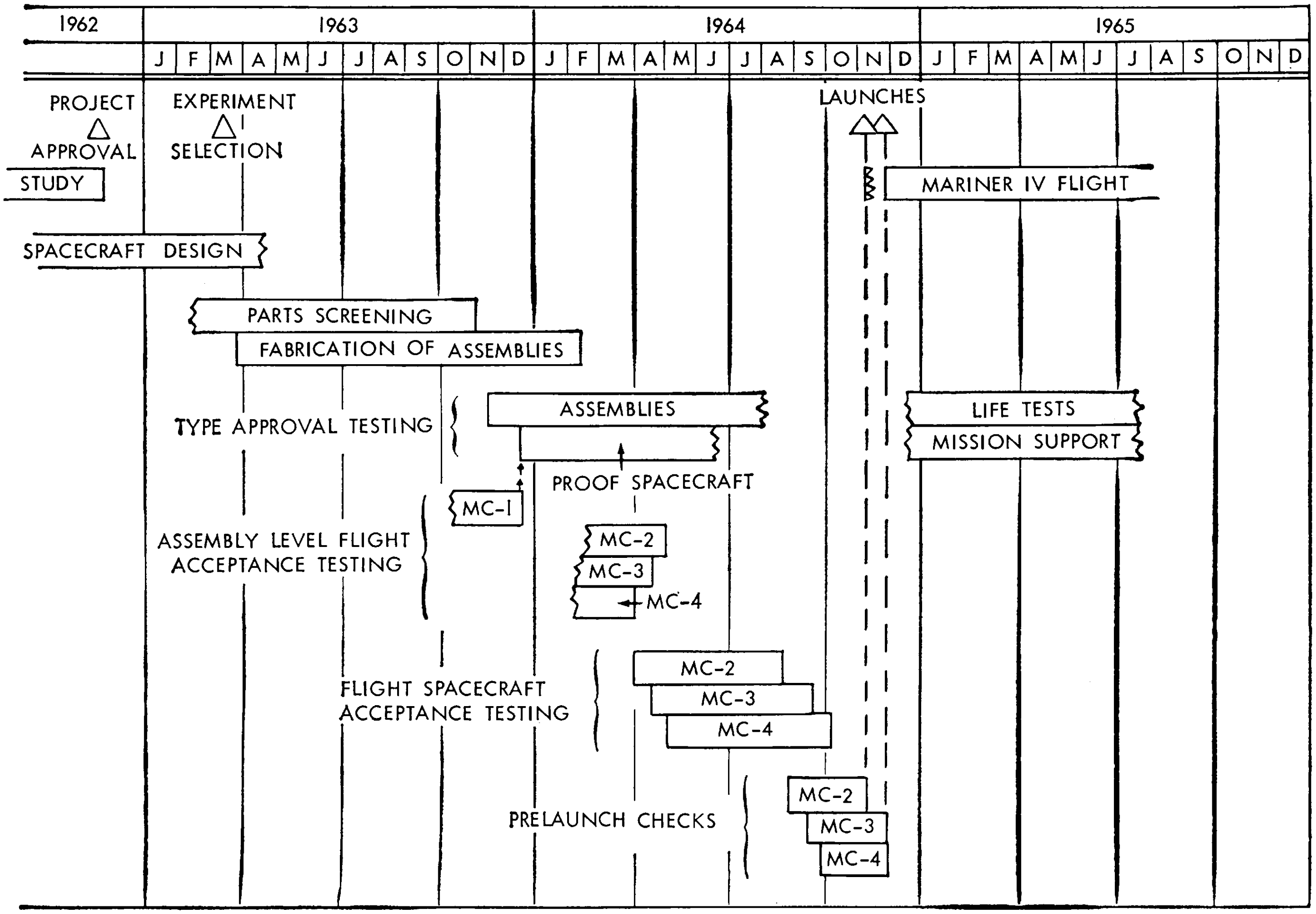

Fig. 1. The phasing of the Mariner IV Project.

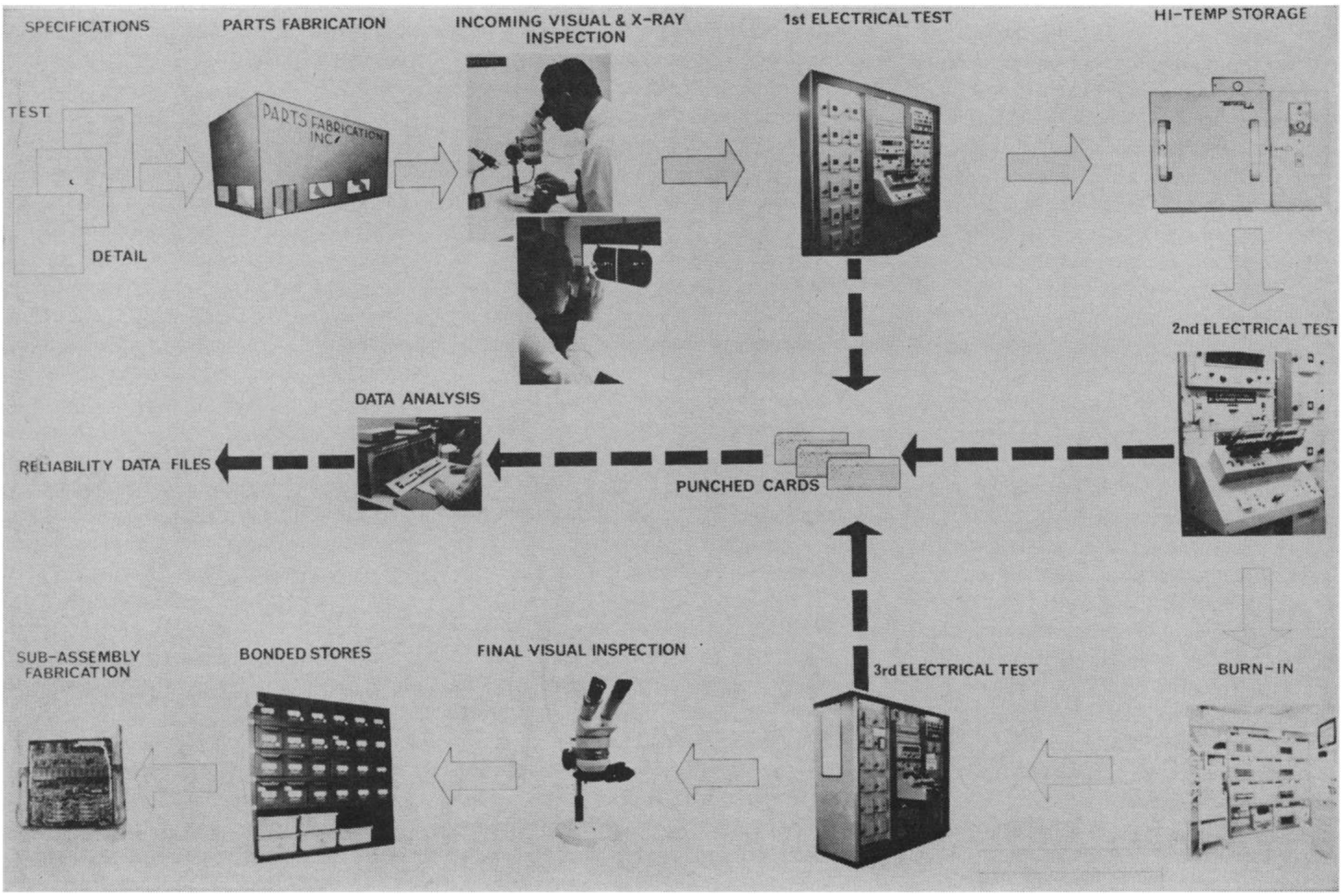

Fig. 2. The stages of the parts-control program for Mariner IV.

mapping. When these integration tests were satisfactorily completed, the type-approval and flight-acceptance tests on the completed spacecraft could proceed.

Environmental Trials

The various environmental stresses expected during the course of a flight were simulated during many of the flight-acceptance and type-approval tests of the individual assemblies and the complete spacecraft (*6*). Since the purpose of the type-approval tests was to determine whether the design itself was acceptable, greater stresses than expected in flight were usually imposed during these tests.

In actual flight, the spacecraft would have to survive lateral, torsional, and acoustic vibration plus electromagnetic interference during boost; and vacuum, sunlight, and cold space during the remainder of the flight (see *6*). Therefore, the vibration and thermal vacuum tests were probably the most important and most revealing. These environmental tests uncovered a number of subtle design deficiencies.

Over 1600 type-approval and flight-acceptance tests were performed on the assemblies, and some 113 failures were reported. As a result, more than 75 design changes were incorporated. For example, during March 1964, just 8 months before launch, type-approval tests at higher-than-expected temperatures caused a group of resistor values to drift, thereby reducing the performance margins in a portion of the data-handling circuitry. This drift was traced to an apparent chemical incompatibility between the resistors and their potting material. At this late date not all these components could be removed from the spacecraft, but a backup design was substituted in one portion of the system, and other corrective measures were implemented with the remaining equipment.

The value of the environmental tests on each separate assembly is indicated by the fact that only 16 failures occurred during the type-approval and flight-acceptance tests of the complete spacecraft. This number could probably have been further reduced if the equipment had been delivered in time for assembly-level testing to be completed before environmental testing of the spacecraft began. Several of these failures revealed very subtle subsystem or assembly interactions which required talented engineering sleuths to uncover and which would probably have caused the mission to fail.

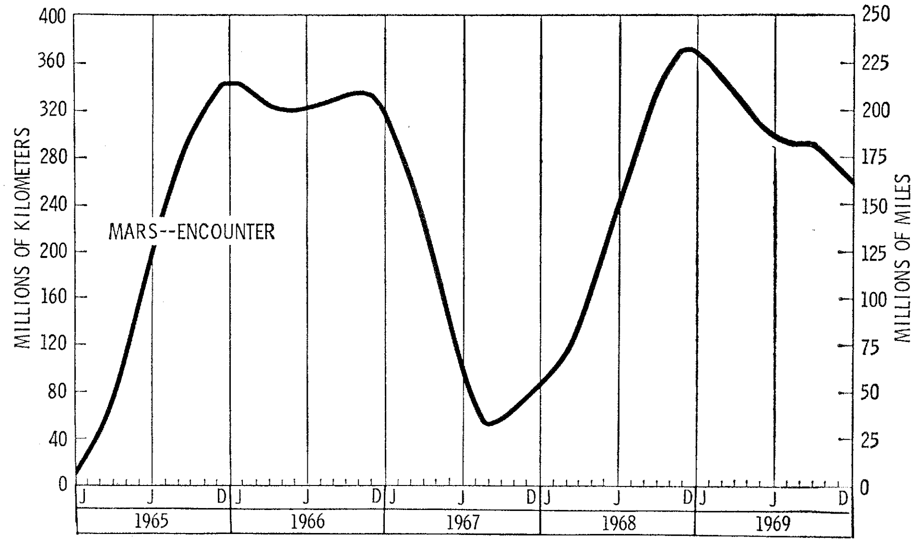

Fig. 3. The distances of Mariner IV from Earth.

Vibration failures occurred in the photomultiplier tube used in the Canopus tracker and in the vidicon used in the television. Redesigns had to be completed before these tubes passed the type-approval vibration tests. In one case the problem was solved by making the tube more rugged, and in the other by isolating the tube.

Common difficulties were traced to electrical breakdown of different dielectrics in the thermal-vacuum environment. Arcing and corona discharge in any part of a spacecraft can be devastating to a digital data system, and these effects can occur after the system has been in a vacuum for days. This phenomenon creates one of the most critical problems in the development of spaceworthy hardware.

It was an arcing problem that led to removal of the ultraviolet photometer from the spacecraft. Arcing was first noted in late March 1964 with the proof-model spacecraft after it had been in the thermal-vacuum chamber for almost 10 days. The initial evidence was an occasional loss of synchronization in the data-handling system. At first the loss was thought to have been caused by an error by the operator. Several weeks of study and special tests revealed that the cause was in the power supply for the ultraviolet instrument. Although it was not too late to fix the equipment, it was too late to adequately validate the change within the spacecraft system. Unfortunately, the only alternative was to remove the instrument. The sensitivity of the thermal and mechanical balance of the spacecraft made it necessary to substitute a nonfunctioning assembly which had the same external characteristics as the ultraviolet photometer.

Four spacecraft operated in the thermal-vacuum chamber for a total of approximately 1100 hours before they were ready for shipment and committed to launch.

Operational Spacecraft

For a successful mission, the spacecraft had to be compatible with the launch vehicle and its shroud, the environment of the launch complex at Cape Kennedy and within the Eastern Test Range, with the Deep Space Instrumentation Facilities, and with the Space Flight Operations Facility.

Many of these compatibility or interface tests were conducted during the prelaunch checks at Cape Kennedy. In late September an all-up combined-system test which involved the actual flight equipment, launch complex, and launch teams was conducted. This test was followed by calibrations of the scientific instruments, magnetic mapping of the spacecraft, final flight-acceptance tests, electrical tests in the explosive-safe area, tests of the operational readiness of the Deep Space Network, simulated launches, and the actual countdowns and launches.

As these activities proceeded, a few

failures or apparent malfunctions occurred in various elements of the total complex. Of course, the most serious was the failure of the launch-vehicle shroud to separate during the launch of Mariner III.

One anomaly, which demonstrates the need for exhaustive compatibility testing, occurred during the first attempted countdown for the launch of Mariner IV. At about the time the gantry was rolled back from the vehicle, it was reported that the magnetometer was producing abnormal data. It was decided to proceed provisionally with the countdown. When the launch was later postponed and the gantry returned to the vehicle, it was found that the anomaly had been caused by an interaction between the gantry and the magnetometer.

Even though schedules would not allow many of the life tests to begin until about the time of launch, these tests proved valuable in assessing the conditions aboard Mariner IV. By means of one such test, the cause of the malfunction of the plasma probe, which occurred about a week after launch, was determined. The plasma-probe unit used in the life test showed similar malfunction after operating for approximately the same amount of time, and the fault was found to be in a power-supply bleeder resistor. Because the location of the fault was known, it has been possible to partially interpret the plasma-probe data received after the rate of telemetry from the spacecraft was reduced from 33⅓ to 8⅓ bits per second.

After launch and during the flight of Mariner IV, the proof-model spacecraft was frequently operated to test various command sequences which had not previously been tried and which were needed to complete the mission. As changes in the operational plans were required during the 7½-month flight of Mariner IV to Mars, alternative procedures were tested and practiced by the operations team with the proof-model spacecraft. Simultaneously, the designers reexamined the "worst-case analyses," and failure modes were simulated.

Thus the interdependent tasks of the engineers and scientists in analyzing, testing, adjusting, rechecking, and sometimes compromising continued from the inception of the development until the mission was successfully completed.

The command to shift the spacecraft antennas did not cause the radiation counters, magnetometer, and cosmic-dust detector to be shut off, and so the spacecraft is continuing to respond to the interplanetary environment. The factors which will most substantially affect the future receipt on Earth of these interplanetary measurements are the performance of the spacecraft and its distance from the Earth. There is nothing inherent in the design of the spacecraft to preclude its operating for another 2 to 4 years. Figure 3 shows that the spacecraft will again be at a distance from Earth which will allow data reception during the summer of 1967. Perhaps at that time we will again be receiving the Mariner IV reports of interplanetary conditions.

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Heterochromatin

Heterochromatin provides a visible guide to suppression of gene action during development and evolution.

Spencer W. Brown

The history of heterochromatin is long and hoary. From the time of the 19th-century cytologists, odd assortments of densely staining flecks, blobs, rods, and agglomerations have been seen in the cell nuclei of various species of plants and animals. Modern insight began in 1928 when Heitz first saw the true relationship of these puzzling structures to the chromosomes, called them heterochromatin, and proposed that heterochromatin had special genetic attributes. The significance of heterochromatin in modern biology is based firmly on its relation to gene action in higher organisms and especially to the integration of gene action during development. Interest in heterochromatin extends from biochemistry and cytogenetics to clinical medicine.

Heitz and the Nuclear Cycle

The typical cell nucleus contains a small, well-defined organelle, the nucleolus, but the bulk of the nucleus appears to be an otherwise structureless maze of tiny dots and threads more or less uniformly dispersed in the nuclear sap and often forming a delicate reticulum. During division of the nucleus (mitosis), the nucleus itself disappears but is represented by the chromosomes. At the onset of mitosis, the dots and threads resolve themselves into elongate chromosomes, which gradually condense to form compact bodies grouped in the center of the cell. At this point, each chromosome splits lengthwise and the two halves separate from each other toward opposite ends of the cell. A specific chromosome region, the centromere, is responsible for the movement of the chromosomes during separation. At the two ends of the cell, the condensation process is reversed; the

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