

How Rosalind Franklin Discovered the Helical Structure of DNA: Experiments in Diffraction

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Rosalind Franklin, a chemical physicist (1920-1958), used x-ray diffraction to determine the structure of DNA. What exactly could she read out from her x-ray pattern, shown in Fig. 1?¹ In lecture notes dated November 1951, R. Franklin wrote the following: "The results suggest a helical structure (which must be very closely packed) containing 2, 3 or 4 co-axial nucleic acid chains per helical unit, and having the phosphate groups near the outside."² This was 16 months before J. D. Watson and F. Crick published their description of DNA, which was based on R. Franklin's x-ray photos. How they gained access to her x-ray photos is a fascinating tale of clashing personalities and male chauvinism.^{2,3}

In this paper we suggest four experiments that enable students to follow in the footsteps of Rosalind Franklin's discovery. We will increase the scale so that it is doable in a high school or undergraduate lab; instead of a tiny DNA molecule, we examine the diffraction pattern of a helical spring from a retractable ballpoint pen, and instead of x-rays we use light rays.^{4,5} These experiments are relatively simple expansions of a regular single-slit or multiple-slits diffraction lab. They have the advantage of giving students a sense for the usefulness of diffraction techniques, something they often miss in "pure" diffraction labs.

The four experiments vary in equipment and difficulty. Experiment 1 uses only simple equipment to illustrate how diffraction reveals the structure of an object. Experiment 2 requires a slightly more elaborate setup, but also gives more information about the diffracting object. Experiment 3 is an analysis of Photo 51 (Fig. 1), and Experiment 4 is a computational simulation of the diffraction of a helix. Experiments 1, 2, and 3 are also good classroom demonstrations.

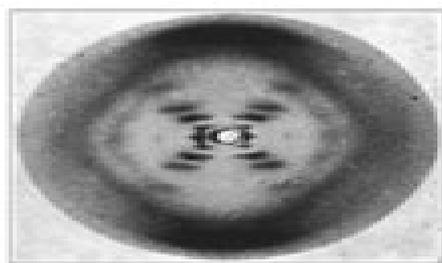


Fig. 1. X-ray diffraction pattern of B-DNA labeled Photo 51 by Rosalind Franklin. The diameter of the largest circle has an original size of 94 mm. At the position of the zero order, a lead disc covered the film to avoid overexposure. The first order is almost blocked by this disc, too. Therefore, we used the second, third, and fifth order for calculation. The fourth order is missing, as explained in the text. (Reprinted with permission from Macmillan Publishers Ltd, Ref. 1).

Experiment 1: Why does the x-shaped pattern reveal the helical structure?

This is a variation on the single-slit experiment with readily available equipment, allowing the student to both see a diffraction pattern similar to Franklin's and to determine the pitch angle α of the helix, as in Fig. 2. If you take the spring from a typical retractable pen and place it on an overhead projector, you observe that the projection of a helix is a sine wave pattern (Fig. 2). We place a laser pointer⁶ or a diode laser (from PASCO) on one end of the lab table and direct the beam (diameter ~ 2 mm) through the side of the spring. (The distance between the laser and spring does not matter.) Holding a white card a couple of centimeters past the spring shows the projection is indeed a sinusoidal pattern and also reveals the number of illuminated pitches. (The shadow will not look sinusoidal if the helix is not oriented perpendicular to the beam.) Since the diameter of the beam is small, it will only illuminate one pitch, i.e., one turn of the helix and only the relatively straight parts of the sine wave, not the curved maxima or minima. We project our diffraction pattern on a screen or wall at least 2 m away, with a larger distance (~ 4 m) better, since it gives a larger pattern. A mirror can be used to fold the path, allowing for a larger distance on a shorter table.

Babinet's principle states that the diffraction pattern of an obstacle is the same as the diffraction pattern of an aperture of the same shape.⁷ According to this principle, the diffraction pattern formed by the two straight sections of the wire (one on each side) is equivalent to the diffraction pattern of two single slits oriented at a certain angle with respect to each other (see Fig. 2). When comparing the diffraction pattern of the helical spring (similar to Fig. 4) with the x-ray diffraction pattern of

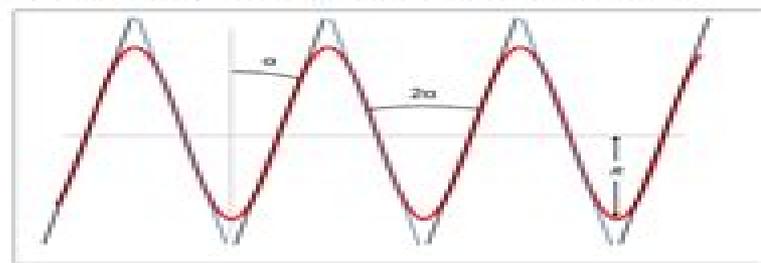


Fig. 2. Here we see the approximately parallel lines formed by the sine wave. We also see the pitch angle α and the radius R .

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