forensic accountants and prosecutors in targeting those responsible for excessively accelerated recognition of revenue.

In presentations of plans, schemes, and strategies, bullet outlines get all confused even about simple, one-way causal models. Here, again from the *Harvard Business Review*, an analysis of bullets for business plans:

> Bullets leave critical assumptions about how the business works unstated. Consider these major objectives from a standard five-year strategic plan
>
> - Increase market share by 25%.
> - Increase profits by 30%.
> - Increase new-product introductions to ten a year.
>
> Implicit in this plan is a complex but unexplained vision of the organization, the market, and the customer. However, we cannot extrapolate that vision from the bullet list. The plan does not tell us how these objectives tie together and, in fact, many radically different strategies could be represented by these three simple points. Does improved marketing increase market share, which results in increased profits (perhaps from economies of scale), thus providing funds for increased new-product development?
>
> Market share ⟶ Profits ⟶ New-product development
>
> Or maybe new-product development will result in both increased profits and market share at once:
>
> New-product development ⟶ Market share
> New-product development ⟶ Profits
>
> Alternatively, perhaps windfall profits will let us just buy market share by stepping up advertising and new-product development:
>
> Profits ⟶ New-product development ⟶ Market share.[18]

It follows that more complex and realistic multivariate causal models are way over the head of the simplistic bullet-list format.

For scientists and engineers, a good way to help raise the quality of an analysis is to ask "What would Richard Feynman do?" The Feynman Principle helps with technical reporting. Feynman experienced the intense bullet outline style in his work on the first shuttle accident, the Challenger in 1986. He expressed his views clearly:

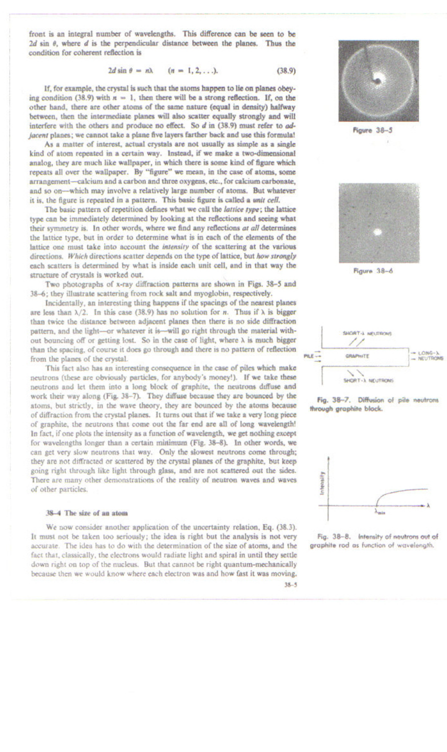
> Then we learned about "bullets"—little black circles in front of phrases that were supposed to summarize things. There was one after another of these little goddamn bullets in our briefing books and on slides.[19]

As analysis becomes more causal, multivariate, comparative, evidence-based, and resolution-intense, the more damaging the bullet list becomes. Scientists and engineers have communicated about complex matters for centuries without bullets. Richard Feynman wrote about much of physics—from classical mechanics to quantum electrodynamics—in three famous textbook volumes totalling 1800 pages. Those books use no bullets and only 2 levels of hierarchy, chapters and subheads within chapters. ⟶

[18] Gordon Shaw, Robert Brown, Philip Bromiley, "Strategic Stories: How 3M is Rewriting Business Planning," *Harvard Business Review*, 76 (May-June, 1998), 44.

[19] Richard P. Feynman, *"What Do You Care What Other People Think?"* (New York, 1988), 126–127.

Page layout from Richard P. Feynman, Robert B. Leighton, and Matthew Sands, *The Feynman Lectures on Physics* (1963), vol. 1, 38.5:



front is an integral number of wavelengths. This difference can be seen to be $2d \sin\theta$, where d is the perpendicular distance between the planes. Thus the condition for coherent reflection is

$$2d \sin\theta = n\lambda \qquad (n = 1, 2, \ldots). \tag{38.9}$$

If, for example, the crystal is such that the atoms happen to lie on planes obeying condition (38.9) with $n = 1$, then there will be a strong reflection. If, on the other hand, there are other atoms of the same nature (equal in density) halfway between, then the intermediate planes will also scatter equally strongly and will interfere with the others and produce no effect. So d in (38.9) must refer to *adjacent* planes; we cannot take a plane five layers farther back and use this formula!

As a matter of interest, actual crystals are not usually as simple as a single kind of atom repeated in a certain way. Instead, if we make a two-dimensional analog, they are much like wallpaper, in which there is some kind of figure which repeats all over the wallpaper. By "figure" we mean, in the case of atoms, some arrangement—calcium and a carbon and three oxygens, etc., for calcium carbonate, and so on—which may involve a relatively large number of atoms. But whatever it is, the figure is repeated in a pattern. This basic figure is called a *unit cell*.

The basic pattern of repetition defines what we call the *lattice type*; the lattice type can be immediately determined by looking at the reflections and seeing what their symmetry is. In other words, where we find any reflections *at all* determines the lattice type, but in order to determine what is in each of the elements of the lattice one must take into account the *intensity* of the scattering at the various directions. *Which* directions scatter depends on the type of lattice, but *how strongly* each scatters is determined by what is inside each unit cell, and in that way the structure of crystals is worked out.

Two photographs of x-ray diffraction patterns are shown in Figs. 38–5 and 38–6; they illustrate scattering from rock salt and myoglobin, respectively.

Incidentally, an interesting thing happens if the spacings of the nearest planes are less than $\lambda/2$. In this case (38.9) has no solution for n. Thus if λ is bigger than twice the distance between adjacent planes then there is no side diffraction pattern, and the light—or whatever it is—will go right through the material without bouncing off or getting lost. So in the case of light, where λ is much bigger than the spacing, of course it does go through and there is no pattern of reflection from the planes of the crystal.

This fact also has an interesting consequence in the case of piles which make neutrons (these are obviously particles, for anybody's money!). If we take these neutrons and let them into a long block of graphite, the neutrons diffuse and work their way along (Fig. 38–7). They diffuse because they are bounced by the atoms, but strictly, in the wave theory, they are bounced by the atoms because of diffraction from the crystal planes. It turns out that if we take a very long piece of graphite, the neutrons that come out the far end are all of long wavelength! In fact, if one plots the intensity as a function of wavelength, we get nothing except for wavelengths longer than a certain minimum (Fig. 38–8). In other words, we can get very slow neutrons that way. Only the slowest neutrons come through; they are not diffracted or scattered by the crystal planes of the graphite, but keep going right through like light through glass, and are not scattered out the sides. There are many other demonstrations of the reality of neutron waves and waves of other particles.

38–4 The size of an atom

We now consider another application of the uncertainty relation, Eq. (38.3). It must not be taken too seriously; the idea is right but the analysis is not very accurate. The idea has to do with the determination of the size of atoms, and the fact that, classically, the electrons would radiate light and spiral in until they settle down right on top of the nucleus. But that cannot be right quantum-mechanically because then we would know where each electron was and how fast it was moving.

38–5

Figure 38–5

Figure 38–6

Fig. 38–7. Diffusion of pile neutrons through graphite block.

Fig. 38–8. Intensity of neutrons out of graphite rod as function of wavelength.