

# Absolute, Arbitrary, Relative, or Normalized Scale? How to Get the Scale Right

Graphical presentation is an essential feature of every scientific paper. Clarity and accuracy of the presentation of data in a figure makes a scientific paper stand out. The majority of experimental results are displayed using  $x$ – $y$  plots. Usually,  $x$  is an independent variable such as wavelength, concentration, time, or length and is defined by a scientific unit. The  $y$ -scale, on the other hand, displays a property (e.g., absorbance or intensity) that is dependent on the variable  $x$ .

A key aspect of expressing the  $y$ -axis of an  $x$ – $y$  plot is the definition of the scale, which includes a proper axis title and associated units (Figure 1). When the measurement is absolute,



Figure 1. Which way do I go? Defining the  $y$ -axis scale of an  $x$ – $y$  plot remains a key aspect. (Courtesy of Shutterstock)

the selection of the scale is quite straightforward because there is no ambiguity in the measured values. Absorbance in a spectrum, photocurrent in a  $J$ – $V$  curve of a solar cell, and current in a cyclic voltammogram are examples of actual (or absolute) measured values. However, in some other measurements, properties of different samples are gathered for the purpose of establishing a trend. Because these data might have been collected under different experimental conditions or using samples with different preparations, one needs to employ arbitrary or relative or normalized scales. These terms are frequently misused in the definition of the  $y$ -axis of  $x$ – $y$  plots. This Editorial makes an effort to clarify the differences among these scales and how to use them effectively while representing a set of data.

**Absolute Scale.** The absolute scale represents the original values as measured from an instrument or from the analysis of the data. The values can be reproduced irrespective of the laboratory or instrument manufacturer. For example, the absorbance spectrum of a 10  $\mu\text{M}$  dye solution will exhibit the same values of absorbance regardless of the place of measurement or the person conducting the measurement. Proper scientific units should also be included in the axis title following the variable quantity (e.g., mA for current or mA/cm<sup>2</sup> for current

density.) Exceptions to this rule are absorbance and pH, which have no units because they are the logarithm of the intensity ratio and 1/H<sup>+</sup> ion concentration, respectively. The data presented on an absolute scale provide quantitative information that significantly contributes to data presentation and analysis.

**Arbitrary Scale** (represented as arb. units or a.u.). In measurements wherein absolute values cannot be obtained, one can frequently use the term arb. units (or a.u.). Examples include measured intensity of an XRD spectrum or an emission spectrum. The arbitrary scale chosen for any measurement is dependent on the instrument settings and the experimental conditions. Hence, it is difficult to compare  $y$ -scales of plots with arbitrary units between two different instruments or laboratories. The term “arb. units” (or a.u.), when used to represent the  $y$ -axis, provides *qualitative* guidance. If there are multiple peaks within the same spectrum, it can compare the relative magnitude of different peaks. Figure 2 shows an example of two different spectra on an absolute and an arbitrary scale.

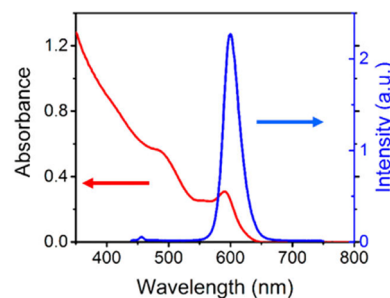
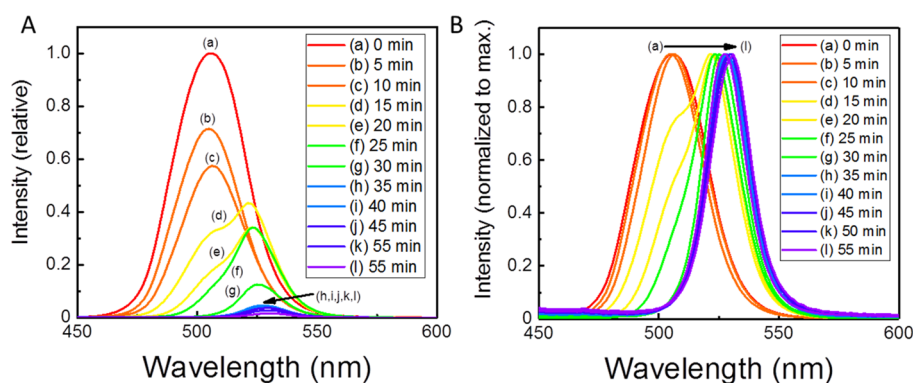


Figure 2. Absorption and emission spectra of CdSe nanocrystals in toluene. Emission spectra were obtained with 420 nm excitation. (Note the absolute scale on the left Y-axis and arbitrary scale on the right Y-axis.) Reprinted from Bridewell, V. L.; Alam, R.; Karwacki, C. J.; Kamat, P. V. *Chem. Mater.* 2015, 27, 5064–5071 (Copyright American Chemical Society).

**Relative Scale.** Relative scale (as the name implies) is related to a reference standard. Multiple measurements using an arbitrary scale, performed under *same set of conditions*, can be compared on a relative scale to establish a trend. For example, emission spectra of a photosensitizer at different quencher concentrations or spectral changes of a system with time can be plotted in relative units. The initial spectrum in these instances serves as a reference to which the other spectra are compared. If one employs a ratio between two sets of data on a relative scale, the derived quantity becomes unitless. The scale is represented as relative (or rel.) units.

**Normalized Scale** (unitless). Normalized units are often employed to compare peak intensities or certain parts of the data. The data presented on a normalized scale represent a ratio,

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**Figure 3.** Photoluminescence spectra illustrating the change in fluorescence with increasing annealing time at 125 °C. (A) Fluorescence of a CsPbBr<sub>3</sub> film from 0 (a, red) to 55 min (l, purple). (B) PL spectra from panel (A) normalized to the maximum intensity to show the gradual shift in emission peak wavelength. Reprinted from Scheidt, R. A.; Atwell, C.; Kamat, P. V. *ACS Mater. Lett.* 2019, 1, 8–13 (Copyright American Chemical Society).

and hence, the scale becomes unitless. Unlike relative scale, the normalized scale employs a normalization factor that *can vary between each set of data* presented within the same plot. Again, normalized scale provides qualitative information to gauge the *trend between different sets of data* on a single plot. It is important to include the criterion used for normalization in the figure caption.

An example showing the difference between relative and normalized scales is shown in Figure 3. A set of emission spectra recorded during the annealing of the CsPbBr<sub>3</sub> film were plotted using a relative scale in Figure 3A. With increasing annealing time, the emission peak decreased, thus showing changes relative to the reference spectrum at  $t = 0$  min. The spectral shifts at longer annealing times, however, are difficult to visualize on this relative scale. Figure 3B shows the same spectra normalized to peak intensity. Each spectrum uses a different multiplication factor so that the peak intensity carries the same value. The normalized plot is useful to visualize the spectral shift observed during the annealing process. The data presented in Figure 3A,B show how the same set of data can be presented on two different scales (viz., relative scale and normalized scale) and provide different information. Thus, one needs to exercise diligence in selecting the right scale so that the data are presented accurately and effectively.



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Prashant V. Kamat, Editor-in-Chief

University of Notre Dame, Notre Dame, Indiana 46556, United States

#### ■ AUTHOR INFORMATION

ORCID

Prashant V. Kamat: 0000-0002-2465-6819

#### Notes

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