❖ Isotope Effects

In the previous section of this chapter, we studied isotopic labeling as a tool to detect the reaction mechanism. There we assumed that the isotopic substitution has no effect on the chemical profile of the reaction whatsoever which is far from the truth because the isotopic substitution can change the rate of chemical reactions in a significant manner.

The changes in the reaction rate when a particular atom in the reactant molecule is replaced by one of its isotopes are termed as isotopic effects.

Formally, it is called as "kinetic isotope effect", and it is calculated rate constants for the reactions with the lighter isotope (k_L) by the rate constant for reaction with the heavier isotope (k_H) i.e.

$$KIE = \frac{k_L}{k_H} \tag{20}$$

This variation in the rate of reaction because the heavier isotopologues have lower vibrational frequencies relative to their lighter isotopes, and can easily be rationalized quantum mechanically. In general, this means that greater energy is needed for heavier isotopologues to cross the transition state (or the dissociation limit in rare cases), and therefore, a lower reaction rate is observed. The kinetic isotopic effect can primarily be classified into two categories; primary and secondary isotope effects.

➢ *Primary Isotope Effects*

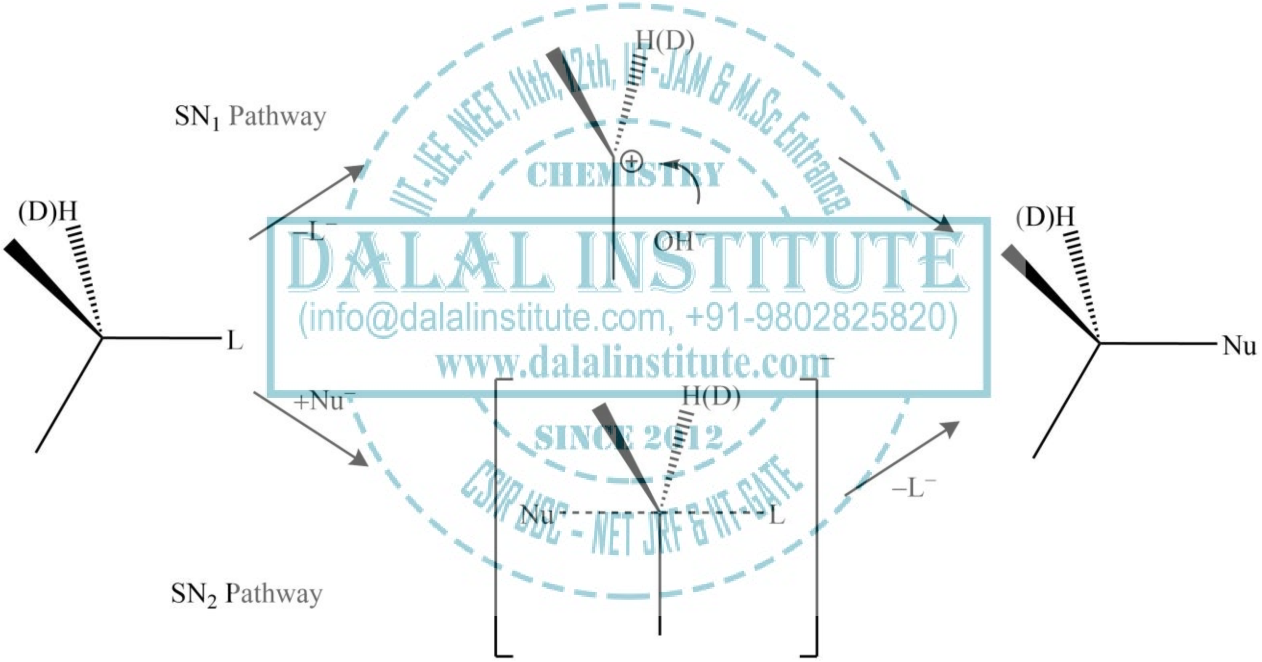
The primary kinetic isotope effect is observed if a bond to the isotopically-labeled atom is being broken or formed. Now depending on the nature of the route followed to study kinetic isotope effect (parallel measurement of rates vs intramolecular competition vs intermolecular competition), we can find if the bond-formation or bond-breaking has happened at the rate-determining step, or in the subsequent product-determining step. Furthermore, it is also worthy to note that many textbooks are propagating the misconception that a primary kinetic isotope effect must echo bond breaking or formation to the isotope at the rate-determining step always.

For nucleophilic substitutions mentioned earlier, the primary kinetic isotope effects have been studied for the attacking nucleophiles, leaving groups, and the α-carbon at which the displacement occurs. The interpretation of the kinetic isotope effects as a function of the leaving group had been very complicated at first because of the significant contributions from temperature-independent factors. Though the primary kinetic isotope effect is less sensitive than the ideal, and the contribution from non-vibrational factors; the kinetic isotope effects at the α-carbon are employed to advance the understanding of the transition state's symmetry of the SN_2 pathway.

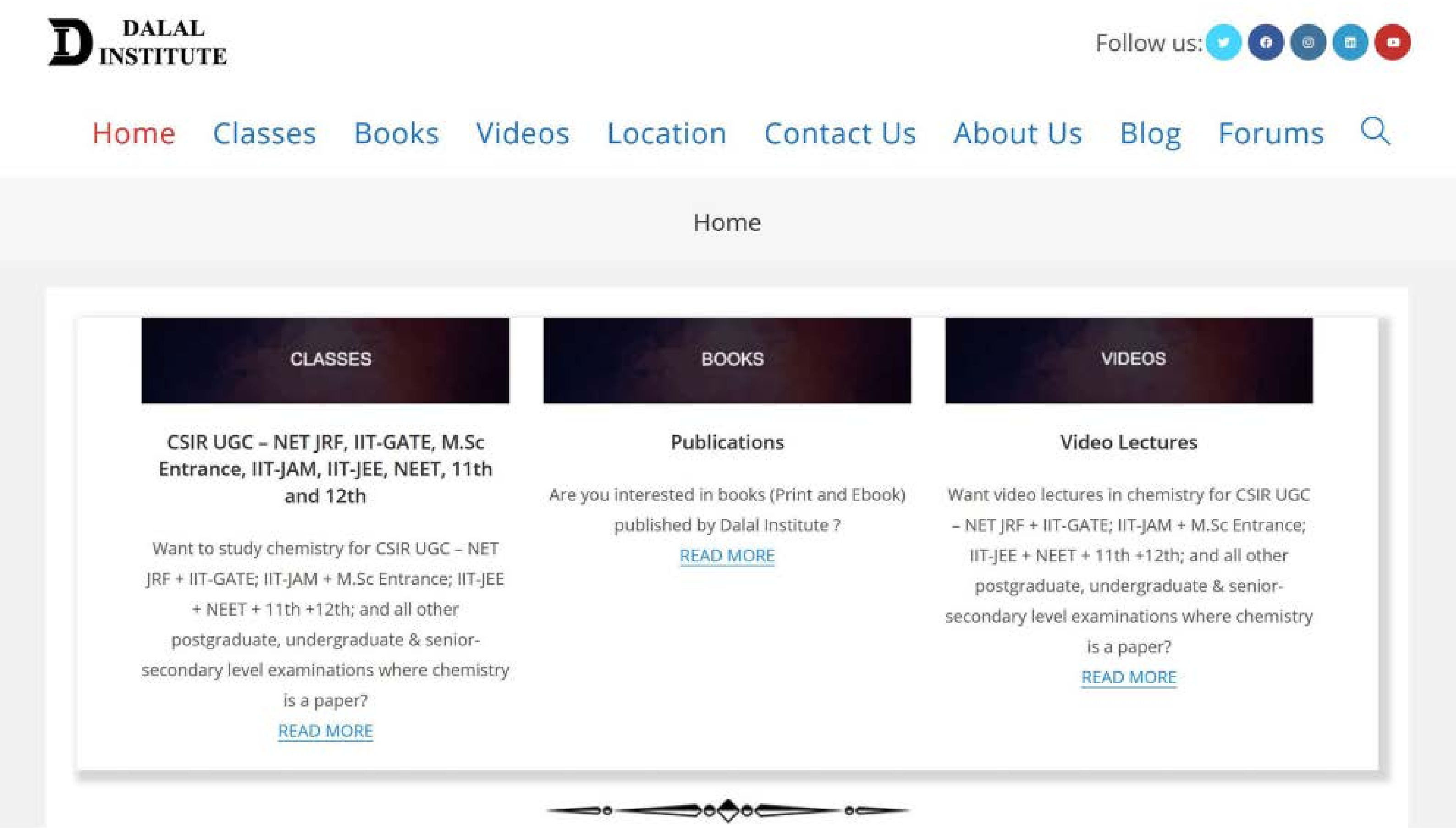
➢ *Secondary Isotope Effects*

We will get a secondary kinetic isotope effect if no bond formation or breaking happens to the isotopically-labeled atom in the reactant. Also, the secondary kinetic isotope effects are much smaller in magnitude than primary kinetic isotope effects; though the secondary isotope effects of deuterium can reach up to 1.4 per atom. Furthermore, many experimental techniques have been invented and refined to measure heavy-element isotope effects with extremely good precision; and therefore, these kinds of effects are still very valuable for mechanisms-elucidating of many organic reactions.

In the case of many nucleophilic substitution reactions, secondary isotope effects of H at α-carbon offer a direct route to differentiate between SN_2 and SN_1 type reactions. It is observed that SN_1 reactions generally give rise to great secondary isotope effects (up to a theoretical maximum of 1.22); whereas SN_2 reactions usually have primary isotope effects which are close to or less than one in most cases. Kinetic isotope effects having a value greater than unity are typically labeled as 'normal kinetic isotope effects', whereas isotope effects having a value less than unity are called as 'inverse kinetic isotope effects'. On the whole, transition states with smaller force constants are expected to have a normal kinetic isotope effect; and transition states with larger force constants are expected to have an inverse kinetic isotope effect when stretching vibrational contributions control the isotope effect.



The Cα-H(D) vibration at the α-carbon dictates the magnitudes of these secondary isotope effects. Now because the carbon is converted into an sp^2 hybridized carbocation during an SN_1 reaction, the transition state for the rate-limiting step will have an increase in Cα-H(D) bond order; and therefore, an inverse kinetic isotope effect would be expected if only the stretching vibrations were the chief factors. On the other hand, large normal kinetic isotope effects are observed which are induced by significant out-of-plane bending vibrational contributions if we go from the reactants to the transition state of carbocation formation. In the case of SN_2 reactions, bending vibrations will still play a vital role in the kinetic isotope effect, but stretching vibrational contributions are also of significant importance; and therefore, the resulting isotope effect may be inverse or normal depending upon the dominating factor.


DALAL INSTITUTE

Follow us:

Home Classes Books Videos Location Contact Us About Us Blog Forums

Home

CLASSES

CSIR UGC – NET JRF, IIT-GATE, M.Sc Entrance, IIT-JAM, IIT-JEE, NEET, 11th and 12th

Want to study chemistry for CSIR UGC – NET JRF + IIT-GATE; IIT-JAM + M.Sc Entrance; IIT-JEE + NEET + 11th +12th; and all other postgraduate, undergraduate & senior-secondary level examinations where chemistry is a paper?

READ MORE

BOOKS

Publications

Are you interested in books (Print and Ebook) published by Dalal Institute ?

READ MORE

VIDEOS

Video Lectures

Want video lectures in chemistry for CSIR UGC – NET JRF + IIT-GATE; IIT-JAM + M.Sc Entrance; IIT-JEE + NEET + 11th +12th; and all other postgraduate, undergraduate & senior-secondary level examinations where chemistry is a paper?

READ MORE

Postgraduate Level

CSIR UGC – NET JRF & IIT-GATE

First Chemistry Batch
(1st January – 31st May)

Second Chemistry Batch
(1st July – 30th November)

Regular Program

Online Course

Result

Senior-Secondary Level

11TH,12TH, NEET & IIT-JEE

First Chemistry Batch
(1st April – 31st August)

Second Chemistry Batch
(1st October – 28th February)

Regular Program

Online Course

Result

Undergraduate Level

M.SC ENTRANCE & IIT-JAM

First Chemistry Batch
(1st February – 30th June)

Second Chemistry Batch
(1st August – 31st December)

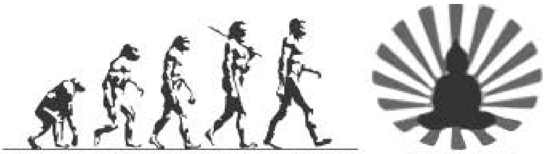
Regular Program

Online Course

Result

Join the revolution by becoming a part of our community and get all of the member benefits like downloading any PDF document for your personal preview.

Sign Up


JOIN THE REVOLUTION FROM BEAST TO BUDDHA

..... India's Best Coaching Center for Academic and Competitive Chemistry Exams .....
(CSIR UGC – NET JRF + IIT-GATE; IIT-JAM + M.Sc Entrance; IIT-JEE + NEET + 11th +12th; and all other postgraduate, undergraduate & senior-secondary level examinations where chemistry is a paper)

DALAL INSTITUTE
.....Chemical Science Demystified.....
Main Market, Sector 14, Rohtak, Haryana 124001, India
(+91-9802825820, info@dalalinstitute.com)
www.dalalinstitute.com

International
Edition

A TEXTBOOK OF ORGANIC CHEMISTRY

Volume I

MANDEEP DALAL

First Edition

DALAL INSTITUTE

Table of Contents

Mandeep Dalal
(M.Sc, Ph.D, CSIR UGC – NET JRF, IIT-GATE)
Founder & Educator, Dalal Institute
E-Mail: dr.mandeep.dalal@gmail.com
www.mandeepdalal.com

Mandeep Dalal is an Indian research scholar who is primarily working in the field of Science and Philosophy. He received his Ph.D in Chemistry from Maharshi Dayanand University, Rohtak, in 2018. He is also the Founder of "Dalal Institute" (India's best coaching centre for academic and competitive chemistry exams), the organization that is committed to revolutionize the field of school-level and higher education in Chemistry across the globe. He has published more than 40 research papers in various international scientific journals, including mostly from Elsevier (USA), IOP (UK), and Springer (Netherlands).

Other Books by the Author

A TEXTBOOK OF INORGANIC CHEMISTRY – VOLUME I, II, III, IV

A TEXTBOOK OF PHYSICAL CHEMISTRY – VOLUME I, II, III, IV

A TEXTBOOK OF ORGANIC CHEMISTRY – VOLUME I, II, III, IV

ISBN: 978-81-952427-3-3
MRP: Rs 800.00

DALAL INSTITUTE
..... Chemical Science Demystified .....
Main Market, Sector 14, Rohtak, Haryana 124001, India
(info@dalalinstitute.com, +91-9802825820)
www.dalalinstitute.com