

## Declaration

I hereby declare that the work presented in this Thesis titled *Nuclear Magnetic Resonance (NMR) investigation of molecular interactions in model drug delivery systems* submitted to the Indian Institute of Technology Jodhpur in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out under the supervision of Dr. Samanwita Pal. The contents of this thesis in full or in parts, have not been submitted to, and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.

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## Certificate

This is to certify that the thesis titled *Nuclear Magnetic Resonance (NMR) investigation of molecular interactions in model drug delivery systems*, submitted by *Deepak Kumar* (PG201383501) to the Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

*Samanwita Pal*  
Ph.D. Thesis Supervisor



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*Deepak Kumar*  
Ph.D. Student





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## List of Symbols

| <b>Symbol</b>         | <b>Description</b>                                    |
|-----------------------|---|
| Å                     | Angstrom  |
| $B_0$                 | Static magnetic field                                 |
| $\beta$               | Full width at half maximum of a XRD peak              |
| °C                    | Degree Celsius  |
| D                     | Diffusion coefficient                                 |
| $D_0$                 | Intrinsic diffusion coefficient                       |
| d                     | Delay   |
| dB                    | Decibel   |
| $\Delta$              | Diffusion delay                                       |
| $\Delta E$            | Difference in energy between nuclear-spin populations |
| $\delta$              | Chemical shift/Gradient length                        |
| $\delta_{\text{ppm}}$ | Chemical shift in parts per million                   |
| $\Delta\delta$        | Chemical shift change                                 |
| E                     | Energy  |
| $E_g$                 | Bandgap   |
| $F_1$                 | Frequency dimension-1                                 |
| $F_2$                 | Frequency dimension-2                                 |
| $\gamma$              | Gyromagnetic ratio                                    |
| G                     | Amplitude of the applied gradient                     |
| g                     | Gram  |
| Hz                    | Hertz   |
| h                     | Planck's constant                                     |
| $I$                   | Density operator for Nuclear spin                     |
| $J$                   | Spectral density/Coupling constant                    |
| K                     | Kelvin  |
| $K_a$                 | Association/Binding constant                          |
| k                     | Chemical exchange rate                                |
| L                     | Litre   |
| $\lambda$             | Wavelength  |
| M                     | Molar concentration                                   |
| $M_0$                 | Net equilibrium magnetization                         |
| $\mu$                 | Magnetic moment                                       |
| $\nu$                 | Frequency of nuclear precession                       |
| $\eta$                | NOE efficiency  |
| $\omega_1$            | Transmitter frequency offset                          |
| Q                     | Quartet   |
| $\rho$                | Auto-relaxation rate                                  |
| $R_1$                 | Spin lattice relaxation rate                          |
| $R_1^{bs}$            | Bi-selective spin lattice relaxation rate             |
| $R_1^{ns}$            | Non-selective spin lattice relaxation rate            |
| $R_1^{se}$            | Selective spin lattice relaxation rate                |
| $R_2$                 | Spin spin relaxation rate                             |
| r                     | Mole ratio  |
| $r_H$                 | Hydrodynamic radius.                                  |
| $r_{ij}$              | Internuclear distance                                 |
| s                     | Second  |
| $\sigma$              | Cross relaxation rate                                 |
| t                     | Time  |

|          |  |
|----------|--|
| $t_1$    | Evolution period   |
| $t_2$    | Acquisition period   |
| $\tau$   | Recovery periods   |
| $\tau_c$ | Molecular rotational correlation time                        |
| $\tau_m$ | Mixing time  |
| $\theta$ | Angle  |
| $T$      | Temperature  |
| $T_1$    | Spin-Lattice relaxation time                                 |
| $T_2$    | Spin-Spin relaxation time                                    |
| $T_d$    | Data points  |
| $\omega$ | Angular frequency/ Larmor frequency                          |
| $W$      | Transition probability between different relaxation pathways |

## List of Abbreviations

| <b>Abbreviation</b> | <b>Full form</b>   |
|---------------------|--|
| AFM                 | Atomic Force Microscopy                                  |
| ASP                 | Aspirin  |
| $\beta$ -CD         | Beta-cyclodextrin  |
| CB                  | Cucurbituril   |
| CDs                 | Cyclodextrins  |
| CEST                | Chemical Exchange Saturation Transfer                    |
| CP                  | Cross Polarization                                       |
| CP-MAS              | Cross Polarization Magic Angle Spinning                  |
| CPMG                | Carr-Purcell-Meiboom-Gill sequence                       |
| COSY                | COrrrelation SpectroscopY                                |
| CSA                 | Chemical Shift Anisotropy                                |
| CS                  | Crystallite Size   |
| CW                  | Continuous wave  |
| DCM                 | Dichloromethane  |
| DDS                 | Drug Delivery System                                     |
| DFL                 | Diffunisal   |
| DFT                 | Density Functional Theory                                |
| D <sub>2</sub> O    | Deuterium Oxide  |
| DMSO-d <sub>6</sub> | Dimethylsulphoxide-d <sub>6</sub>                        |
| DSC                 | Differential Scanning Calorimetry                        |
| d                   | doublet  |
| dd                  | doublet of doublet                                       |
| dt                  | doublet of triplet                                       |
| DOSY                | Diffusion Ordered Spectroscopy                           |
| DOX                 | Doxorubicin  |
| DNR                 | Daunorubicin   |
| EMA                 | European Medicine Agency                                 |
| EXSY                | EXchange SpectroscopY                                    |
| FDA                 | Food and Drug Administration                             |
| FID                 | Free Induction Decay                                     |
| FT                  | Fourier Transformation                                   |
| FTIR                | Fourier-Transform Infrared spectroscopy                  |
| GAMESS              | General Atomic and Molecular Electronic Structure System |
| GRAS                | Generally Recognized As Safe                             |
| HETCOR              | HETeronuclear COrrrelation spectroscopy                  |
| HP- $\beta$ -CD     | Hydroxypropyl-beta-cyclodextrin                          |
| IR                  | Infrared   |
| kHz                 | Kilo Hertz   |
| kJ/mol              | Kilojoules per mole                                      |
| kcal                | Kilocalorie  |
| kDa                 | Kilo Dalton  |
| MAS                 | Magic angle spinning                                     |
| MD                  | Molecular dynamics                                       |
| MHz                 | Mega hertz   |
| MT                  | Magnetization Transfer                                   |
| MW                  | Molecular Weight   |
| mg                  | Milligrams   |
| mM                  | Millimolar   |

|        |   |
|--------|---|
| mL     | Milliliter                                    |
| μs     | Microsecond                                   |
| NMR    | Nuclear magnetic resonance                    |
| NOE    | Nuclear Overhauser Enhancement                |
| NOESY  | Nuclear Overhauser Effect Spectroscopy        |
| NPs    | Nanoparticles                                 |
| NS     | No. of scans                                  |
| nm     | Nanometer                                     |
| ns     | Nanosecond                                    |
| w/o    | Water-in-Oil                                  |
| w/o/w  | Water-in-Oil-in-Water                         |
| w/v    | Weight by Volume                              |
| PC     | Paracetamol                                   |
| PDB    | Protein Data Bank                             |
| PGA    | Poly-Glycolic Acid                            |
| PFGSE  | Pulsed field Gradient Stimulated Echo         |
| PLA    | Poly-Lactic Acid                              |
| PLGA   | Poly(lactic-co-glycolic acid)                 |
| PPM    | Parts per million                             |
| RAMP   | Ramped-amplitude                              |
| REDOR  | Rotational Echo Double Resonance              |
| RF     | Radio frequency                               |
| RSP    | Risperidone                                   |
| ROE    | Rotating frame Overhauser Enhancement         |
| ROESY  | Rotating-frame Overhauser Effect Spectroscopy |
| ROS    | Reactive Oxygen Species                       |
| SEM    | Scanning Electron Microscopy                  |
| S/N    | Signal-to-noise ratio                         |
| SS-NMR | Solid State Nuclear Magnetic Resonance        |
| STD    | Saturation Transfer Difference                |
| SW     | Spectral width                                |
| TEM    | Transmission Electron Microscopy              |
| UV-DRS | Ultraviolet Diffuse Reflectance Spectroscopy  |
| v/v    | Volume-by-volume                              |
| w/v    | Weight-by-volume                              |
| w/w    | Weight-by-weight                              |
| XRD    | X-Ray Diffraction                             |
| ZnO    | Zinc Oxide                                    |
| 1D     | One-dimensional                               |
| 2D     | Two-dimensional                               |
| 5-FU   | 5-Fluorouracil                                |



