Supporting Information

Hydrazone-based covalent organic frameworks as efficient photocatalytic redox reactions

Jing Feng,[a] Bingjie Yang,[a] Pei Fan,[a] Yongchao Lu,[a] Qing Su,*[a] Boai Li,[a] Qingru Yang,[a] Meng Lei,[a] Hao Ren,[b] and Qiaolin Wu*[a]

[a] *College of Chemistry, Jilin University, 2699 Qianjin Street, Changchun 130012, P. R. China. Emails: suqing@jlu.edu.cn (Q. Su),wuql@jlu.edu.cn (Q. Wu)*

[b]*State Key Laboratory of Inorganic Synthesis and Preparative Chemistry, Jilin University, 2699 Qianjin Street, Changchun 130012, P. R. China.*

Contents

Section S1. Reagents and solvents

All the chemicals are commercially available and used without further purification. Benzaldehyde and its derivatives were purchased from Macklin Co., Ltd. 2-Aminophenylthiol, 2-amino-4-chlorobenzenethiol, hexamethylenetetramine (HMTA), 2,5-dihydroxyterephthalic acid, resorcinol, deuterated solvents for NMR measurement were purchased from Aladdin Industries Inc. 2,2,6,6-Tetramethylpiperidine oxide (TEMPO, 98%), 5,5-dimethyl-1-pyrroline N-oxide (DMPO, 98%), benzoquinone (AR), sodium azide (NaN_3, AR), potassium iodide (KI, 99%), copper sulfate ($CuSO_4$) were purchased from Macklin Inc. Ethanol (EtOH), methanol (MeOH), tetrahydrofuran (THF), acetonitrile (CH_3CN), mesitylene and 1,4-dioxane were purchased from Beijing Chemical Plant Co., Ltd. Trifluoroacetic acid (TFA), phenol, hydrazine hydrate were purchased from Tianjin Fuyu Co., Ltd. The monomers were synthesized according to the reported methods. [1–4]

Section S2. The characterization

2.1 The Fourier Transform Infrared (FT-IR) spectroscopy

The Fourier Transform Infrared (FT-IR) spectroscopy was recorded on a Nicolet is5 spectrometer using KBr pellets within the wavenumber range 400 to 4000 cm^{-1}.

2.2 Nuclear magnetic resonance (NMR) spectroscopy

^1H NMR and ^{13}C NMR spectra were carried out on a Bruker-Avance III 400 MHz spectrometer. The solid-state ^{13}C CP/MAS NMR measurement was recorded using a Bruker AVANCE III 400 WB spectrometer.

2.3 Powder X-ray diffraction (PXRD)

PXRD data was collected on a PANalytical BV Empyrean diffractometer with a 2θ range of 1° to 30° at 298 K. The Pawley refinement of the experimental PXRD was conducted by the Reflux module in the Material Studio 2019.

2.4 Thermogravimetric analysis (TGA)

Thermogravimetric analyses (TGA) were recorded from room temperature to 800 °C with a heating rate of 10 °C/min on a NETZSCH STA449 F3 thermal analyzer under a N_2 atmosphere.

2.5 Nitrogen adsorption-desorption isotherm measurements (BET)

The N_2 adsorption and desorption isotherms were performed at 77 K with a Micromeritics ASAP 2020M system. The Brunauer-Emmett-Teller (BET) method was used to calculate surface area and pore volume. Nonlocal density functional theory (NLDFT) was utilized to analyze the pore size distributions.

2.6 X-ray photoelectron spectroscopy (XPS)

X-ray photoelectron elemental distribution binding energy and valence band (VB) energy were obtained by Thermo ESCALAB 250 X-ray photoelectronic spectrometer.

2.7 UV-visible absorption spectra (Solid) and Kubelka-Munk function

The solid-state UV-Vis diffuse reflectance spectra were recorded from 200 to 800 nm on a Shimadzu UV-4100-NIR spectrophotometer. The variation relationship between the diffuse reflectance of a solid sample and wavelength was measured using spectrophotometer. It is worth noting that R_∞ was the diffuse reflectance of the sample. The Kubelka-Munk function is difined according to the formula:

$$F(R_\infty) = \frac{(1 - R_\infty)^2}{2R_\infty}$$

Typically, the wavelength can be converted into photon energy (hν) using the conversion formula:

$$h\nu = \frac{hc}{\lambda}$$

where h is Planck's constant, c is the speed of light, and λ is the wavelength. The band gap Eg is calculated from the Tauc plot graph, where $(F(R_\infty)h\nu)^2$ is plotted against the photon's energy $h\nu$. Subsequently, we constructed a plot with $(F(R_\infty)h\nu)^2$ as the vertical axis and $h\nu$ as the horizontal axis. By extending the linear portion of the curve to its intersection with the horizontal axis, the value at this intersection corresponds to the band gap energy Eg of the material.

2.8 Scanning electron microscopy (SEM) and high-resolution transmission electron microscopy (HR-TEM)

Scanning electron microscopy (SEM) and high-resolution transmission electron microscopy (HR-TEM) images were obtained by a Hitachi SU8020 microscope and a Tecnai G2 S-Twin F20 field-emission transmission electron microscope, respectively.

2.9 The water contact angle experiment

The water contact angle experiment was tested using a DSA-25-KRÜSS GMBH goniometer.

2.10 Photoluminescence (PL) spectroscopy

The Solid-state fluorescence and fluorescence lifetime were performed on an Edinburgh Instrument FLS920 spectrometer.

2.11 Electron Paramagnetic Resonance (EPR) test

The electron paramagnetic resonance (EPR) spectra were acquired using a Bruker EMXnano ESR spectrometer. 1 mg of COF sample was suspended in 1 mL of methanol, followed by the addition of 5 μL of DMPO. The mixture was subsequently drawn into a capillary tube, which was then placed in EPR specific tube for further radical production and detection. EPR spectra was acquired with scanning width of 100 G, scanning power of 1 mW, central field of 3350 G, sweep time of 40s and temperature of 25°C.

Section S3. Electrochemical measurements

Photoelectrochemical measurements were taken at room temperature on the instrument workstation (CHI760E, China) using a standard three-electrode system. The system included a platinum wire electrode as an assistant electrode, an Ag/AgCl reference electrode, and a glassy carbon electrode as a working electrode.

3.1 EIS measurement

Sample preparation: 5 mg of the material was added to a centrifuge tube containing anhydrous ethanol (225 μL), deionized water (225 μL), and 50 μL *N*-methylpyrrolidone (NMP) solution of 1.5 wt% polyvinylidene fluoride (PVDF). The impedance tests were carried out in a 0.1 mol L^{-1} KCl solution containing 5 mmol L^{-1} $[Fe(CN)_6]^{3-/4-}$.

3.2 Mott-Schottky and photocurrent measurements

The 0.1 mol L^{-1} Na_2SO_4 solution as electrolyte was employed to carry out Mott-Schottky and photocurrent measurements. 5 mg of COF was dispersed with 1 mL EtOH containing 10 µL of 5% Nafion. The suspension was meticulously placed onto the glassy carbon electrode and subsequently subjected to a drying process at 70 °C for 20 minutes. Mott-Schottky measurement was conducted in 0.1 mol L^{-1} Na_2SO_4 solution at 1000, 1500, and 2000 Hz frequencies with 5 mV amplitude. The photocurrent measurements were performed in 0.1 mol L^{-1} Na_2SO_4 aqueous solution under a 300 W Xe lamp irradiation.

Section S4. Synthesis of MOH-$Tf1_1Tf2_2$

Place **Tf1** (8.9 mg, 0.05 mmol), **Tf2** (19.4 mg, 0.1 mmol), **MOH** (57.2 mg, 0.225 mmol), and a mixed solvent of 1,4-dioxane/mesitylene (1:3, v/v, 2.4 mL) in an ampoule. The mixture was then ultrasonicated for 15 minutes to form a uniform suspension. Next, 0.3 mL of acetic acid solution (6 M) was added with continuing sonication for 10 minutes. The ampoule was flame-sealed after three freeze-pump-thaw cycles and heated at 120 °C for 72 h. The obtained precipitate was filtered and washed alternately with THF (30 mL) and acetone (30 mL) to remove organic residues. The solid was then dried at 80 °C for 24 hours to obtain a yellow powder in an 85% yield.

Section S5. Results and discussion

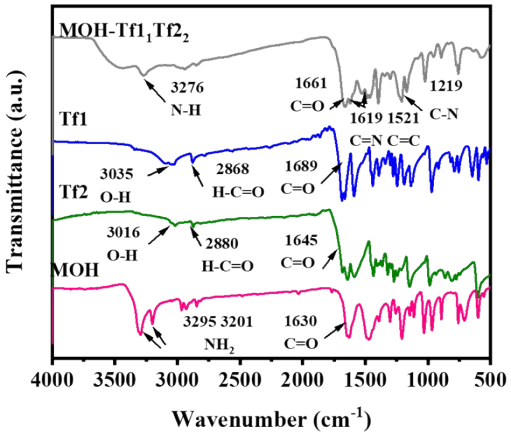


Fig. S1 FT-IR spectra of **MOH-$Tf1_1Tf2_2$** and corresponding monomers.

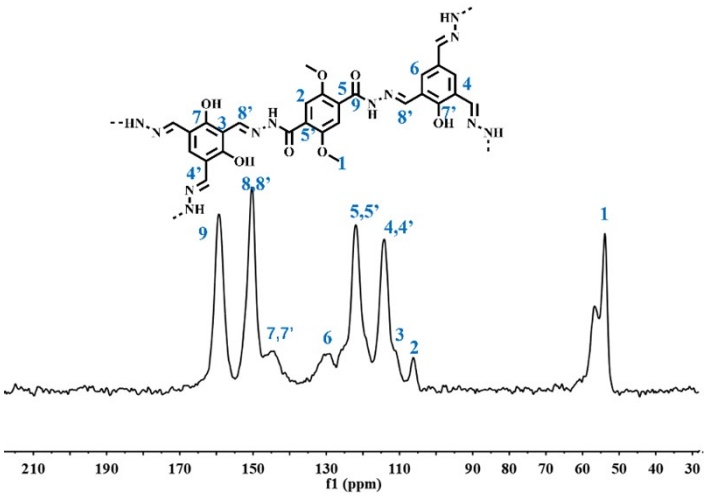


Fig. S2 ^{13}C CP-MAS solid-state NMR spectrum of **MOH-Tf1$_1$Tf2$_1$**.

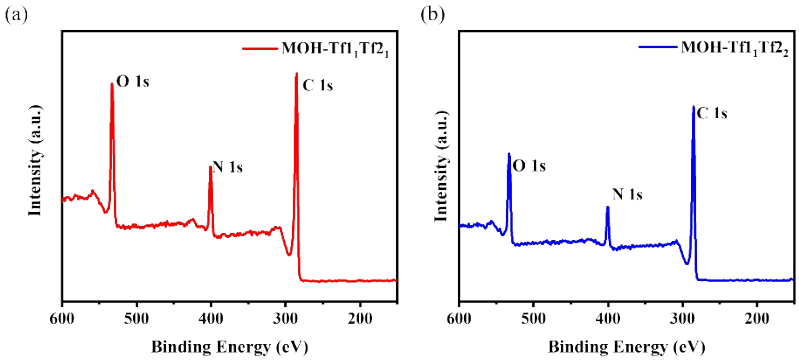


Fig. S3 (a) XPS full-scale survey spectrum of **MOH-Tf1$_1$Tf2$_1$**. (b) XPS full-scale survey spectrum of **MOH-Tf1$_1$Tf2$_2$**.

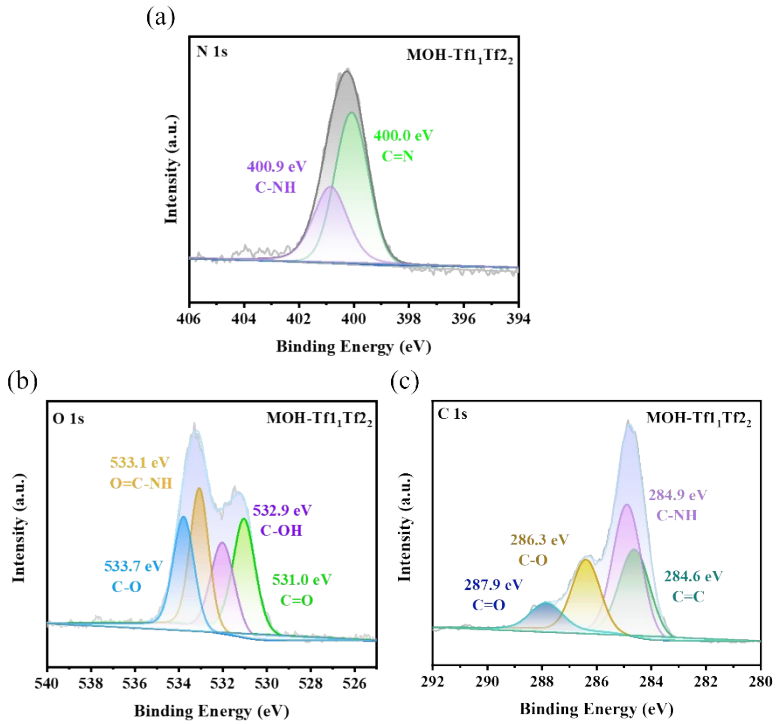


Fig. S4 (a) XPS spectra in the N 1s regions of **MOH-Tf1$_1$Tf2$_2$**. (b) XPS spectra in the O 1s regions of **MOH-Tf1$_1$Tf2$_2$.** (c) XPS spectra in the C 1s regions of **MOH-Tf1$_1$Tf2$_2$.**

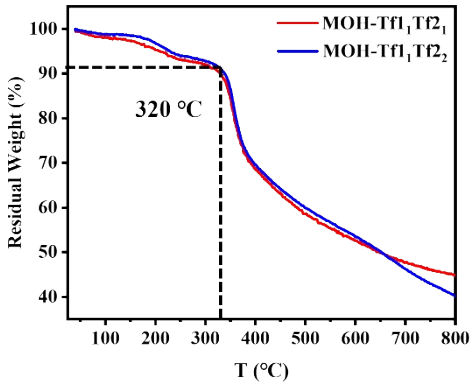


Fig. S5 The TGA curves of **MOH-Tf1$_1$Tf2$_1$** and **MOH-Tf1$_1$Tf2$_2$**.

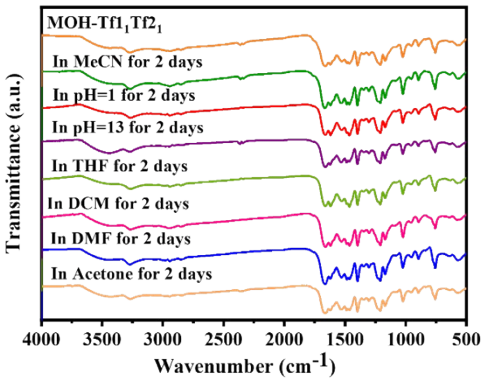


Fig. S6 FT-IR spectra of **MOH-Tf1$_1$Tf2$_1$** before and after treatment in different media for 2 days.

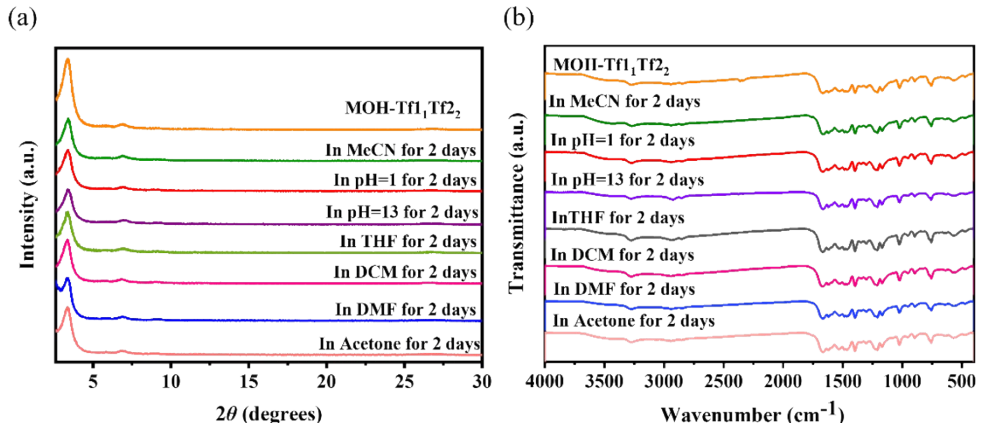


Fig. S7 (a) The PXRD profiles of **MOH-Tf1$_1$Tf2$_2$** before and after treatment in different media for 2 days. (b) FT-IR spectra of **MOH-Tf1$_1$Tf2$_2$** before and after treatment in different media for 2 days.

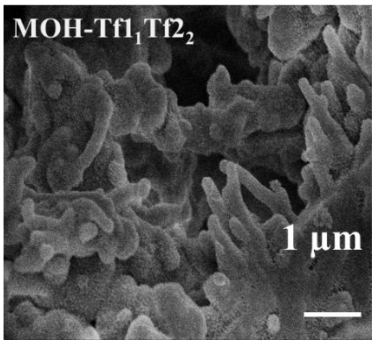


Fig. S8 The SEM of **MOH-Tf1$_1$Tf2$_2$**.

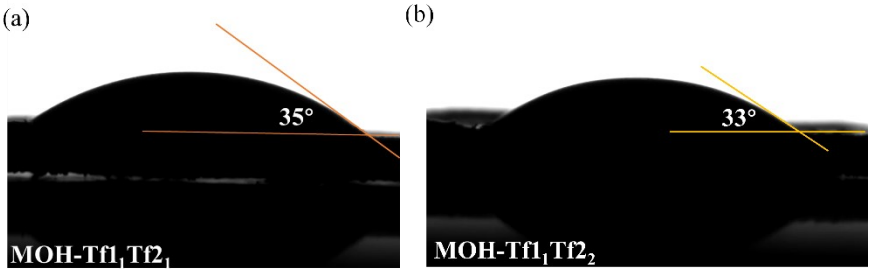


Fig. S9 (a) The water contact angle of **MOH-Tf1$_1$Tf2$_1$**. (b) The water contact angle of **MOH-Tf1$_1$Tf2$_2$**.

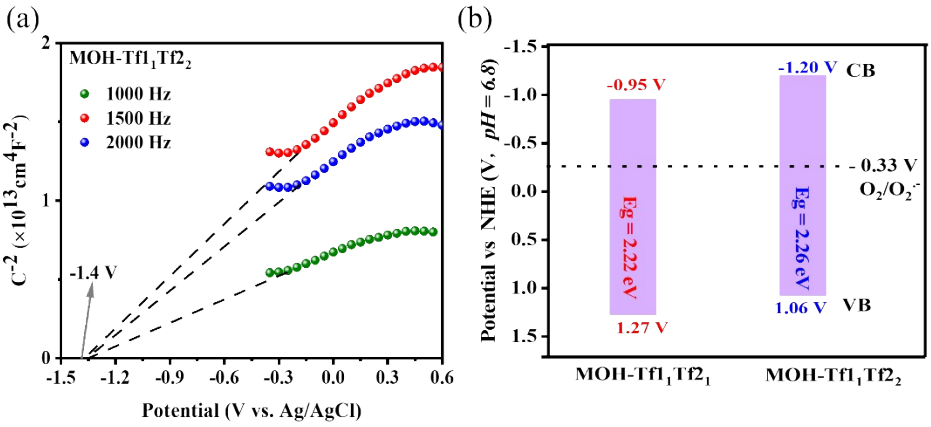


Fig. S10 (a) Mott-Schottky plots of **MOH-Tf1$_1$Tf2$_2$**. (b) Band-structure diagrams of **MOH-Tf1$_1$Tf2$_1$** and **MOH-Tf1$_1$Tf2$_2$**.

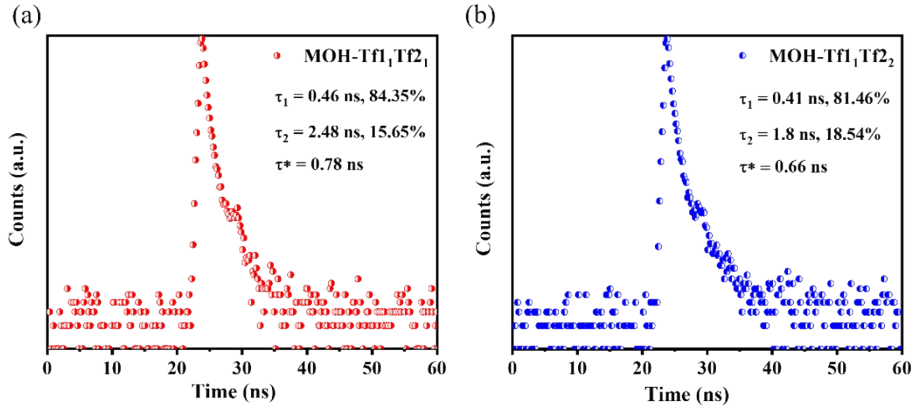


Fig. S11. (a) Fluorescence lifetime spectrum of **MOH-Tf1$_1$Tf2$_1$** upon excitation at 350 nm. (b) Fluorescence lifetime spectrum of **MOH-Tf1$_1$Tf2$_2$** upon excitation at 350 nm.

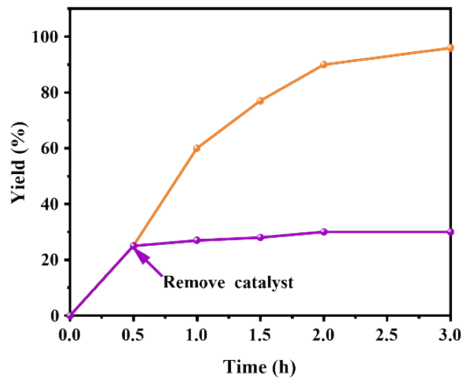
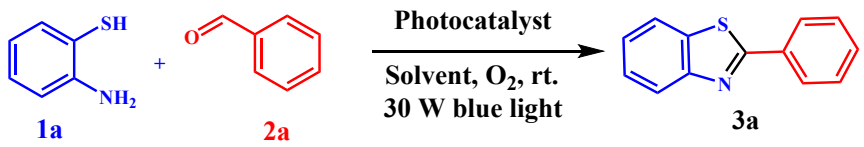


Fig. S12 Kinetic curve and hot filtration experiment of forming 2-phenylbenzothiazole using the MOH-Tf1$_1$Tf2$_1$ as a photocatalyst under visible-light irradiation (The yellow line represents the kinetic curve; and the purple line represents the heat filtration curve).

Table S1. Optimization of the conditions for synthesizing 2-phenylbenzothiazole using **MOH-Tf1$_1$Tf2$_1$** photocatalyst under visible-light irradiation.[a]



Entry	Catalyst	Solvents	Amount of catalyst (mg)	Time (h)	Yield (%)[b]
1	**MOH-Tf1$_1$Tf2$_1$**	THF	3	3	65
2	**MOH-Tf1$_1$Tf2$_1$**	MeCN	3	3	45
3	**MOH-Tf1$_1$Tf2$_1$**	DMF	3	3	55
4	**MOH-Tf1$_1$Tf2$_1$**	EtOH	3	3	82
5	**MOH-Tf1$_1$Tf2$_1$**	MeOH	3	3	85
6	**MOH-Tf1$_1$Tf2$_1$**	H_2O	3	3	60
7	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=1:1	3	3	96
8	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=1:3	3	3	80
9	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=3:1	3	3	89
10	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=1:1	1	3	60
11	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=1:1	2	3	82
12[c]	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=1:1	3	3	trace
13[d]	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=1:1	3	3	trace
14[e]	**MOH-Tf1$_1$Tf2$_1$**	MeOH/H_2O=1:1	3	3	trace
15[f]	**MOH-Tf1$_1$Tf2$_2$**	MeOH/H_2O=1:1	3	3	90

[a]Reaction condition: 2-aminobenzenethiol (0.22 mmol), benzaldehyde (0.2 mmol), photocatalyst (3 mg), and MeOH/H_2O (1.6 mL, v/v = 1:1,) was placed in a 5 mL flask and irradiated with a 30 W blue LED under an O_2 atmosphere at room temperature for 3 h.

[b] Yield of isolated product.

[c] Reaction was carried out under Ar.

[d] Reaction was carried out in the dark.

[e] Reaction was carried out without a photocatalyst.

[f] Reaction was carried out with **MOH-Tf1$_1$Tf2$_2$** as a photocatalyst.

Table S2. Comparison of other catalysts for photocatalytic synthesis of benzothiazole with the catalysts in this paper.

Catalyst	Solvents	Amount of catalyst	Temperature (℃)	Time (h)	Yield (%)	Reference
CMP-Th-Ph-T	MeOH	8 mg	25 ℃	4	99	S5
fluorescein	MeOH	10 mol%	25 ℃	3	92	S6
TPA-MP-1	EtOH	5 mg	25 ℃	3	86	S7
CdNS	MeOH	5 mg	25 ℃	0.5	96	S8
TAPT-TP-COF	EtOH : H_2O=1:1	5 wt%	25 ℃	10	98	S9
[Bmim]PF$_6$	/		110 ℃	2	89	S10
VHb	DMSO	0.05 mol%	25 ℃	12	16	S11
MOH-Tf1$_1$Tf2$_1$	MeOH : H_2O=1:1	3 mg	25 ℃	3	96	*This work*

MOH-Tf1$_1$Tf2$_2$	MeOH : H_2O=1:1	3 mg	25 ℃	3	90	*This work*

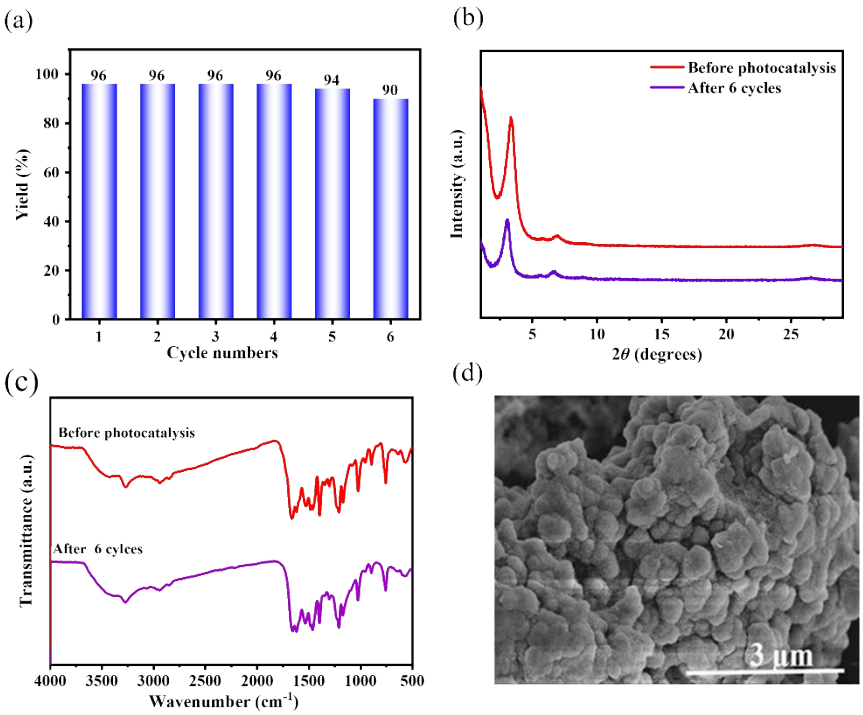
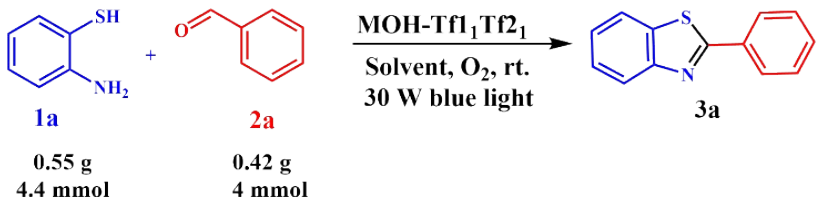


Fig. S13 (a) Catalytic recycle experiments of **MOH-Tf1$_1$Tf2$_1$** as the photocatalyst for the synthesis of 2-phenylbenzothiazole. (b) PXRD patterns of the **MOH-Tf1$_1$Tf2$_1$** before and after six catalytic cycles. (c) The FT-IR spectra of the **MOH-Tf1$_1$Tf2$_1$** before and after six catalytic cycles. (d) SEM image of the **MOH-Tf1$_1$Tf2$_1$** after six cycles.

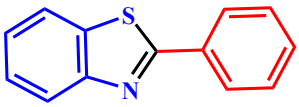


Scheme S1. The large-scale photocatalytic synthesis of 2-phenylbenzothiazole by **MOH-Tf1$_1$Tf2$_1$** (30 mg) as a heterogeneous photocatalyst under optimal conditions.

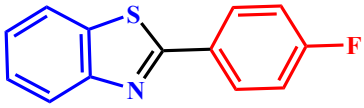
Fig. S14. Detection of H_2O_2 in the reaction mixture of photocatalytic synthesis of 2-phenyl benzothiazole with KI/CH_3COOH. 2-Aminothiophenol (0.22 mmol), benzaldehyde (0.2 mmol) and catalyst **MOH-Tf1$_1$Tf2$_1$** (3 mg) were added into MeOH: H_2O (v/v, 1/1, 1.6 mL). After being irradiated for 3 hours under an O_2 atmosphere, the catalyst was removed. Then, KI (0.1 M aqueous solution) and aqueous acetic acid (0.1 M) were added to the filtrate, resulting in a color change of the reaction

mixture from yellowish to brown.

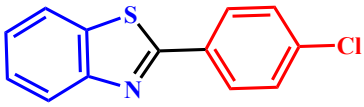
Section S6. NMR data of products



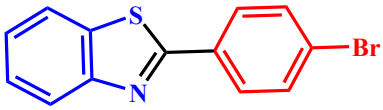
2-phenylbenzo[d]thiazole (**3a).** White solid (40.6 mg, 96%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.08 (d, J = 8.1 Hz, 3H), 7.91 (d, J = 8.0 Hz, 1H), 7.50 (s, 4H), 7.39 (t, J = 7.6 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 168.06, 154.19, 135.11, 133.67, 130.97, 129.03, 127.58, 126.33, 125.20, 123.27, 121.63 ppm.



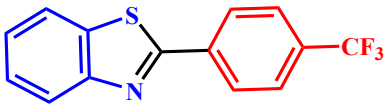
2-(4-fluorophenyl)benzo[d]thiazole (3b).White solid (39.1 mg, 85%).^{1}H NMR (400 MHz, $CDCl_3$): δ 8.25–8.01 (m, 3H), 7.90 (d, J = 7.9 Hz, 1H), 7.50 (t, J = 7.3 Hz, 1H), 7.39 (t, J = 7.6 Hz, 1H), 7.18 (t, J = 8.6 Hz, 2H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.76, 165.71, 163.21, 154.10, 135.05, 129.96 (d, J = 3.2 Hz), 129.53 (d, J = 8.7 Hz), 126.43, 125.33, 123.20, 121.63, 116.29 (d, J = 8.7 Hz) ppm.



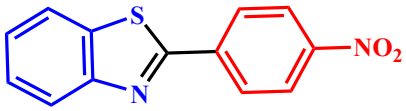
2-(4-chlorophenyl)benzo[d]thiazole (3c).White solid (42.6 mg, 87%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07 (d, J = 8.1 Hz, 1H), 8.02 (d, J = 8.6 Hz, 2H), 7.90 (d, J = 8.0 Hz, 1H), 7.54–7.48 (m, 1H), 7.47 (d, J = 8.6 Hz, 2H), 7.40 (t, J = 8.1 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.63, 154.06, 137.04, 135.05, 132.11, 129.28, 128.71, 126.50, 125.43, 123.31, 121.67 ppm.



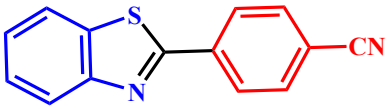
2-(4-bromophenyl)benzo[d]thiazole (3d). Yellow solid (52.0 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07 (d, J = 8.1 Hz, 1H), 7.96 (d, J = 8.4 Hz, 2H), 7.91 (d, J = 7.9 Hz, 1H), 7.63 (d, J = 8.3 Hz, 2H), 7.51 (t, J = 7.6 Hz, 1H), 7.41 (t, J = 7.5 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.71, 154.07, 135.04, 132.55, 132.25,128.92, 126.52, 125.47, 125.44, 123.32, 121.68 ppm.



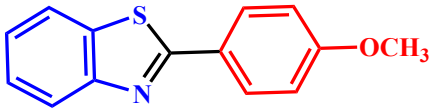
2-(4-(trifluoromethyl)phenyl)benzo[d]thiazole (3e). White solid (49.7 mg, 89%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.20 (d, J = 8.1 Hz, 2H), 8.11 (d, J = 8.1 Hz, 1H), 7.93 (d, J = 7.9 Hz, 1H), 7.75 (d, J = 8.2 Hz, 2H), 7.53 (t, J = 8.2 Hz, 1H), 7.43 (t, J = 8.1 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.05, 154.03, 136.75, 135.20, 132.60, 132.28, 127.77, 126.67, 126.01 (q, J = 3.8 Hz), 125.80, 123.63, 121.76 ppm.



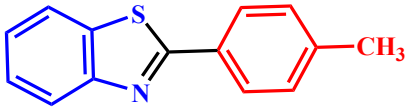
2-(4-nitrophenyl)benzo[d]thiazole (3f).Yellow solid (46 mg, 90%)**.** ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.36 (d, J = 8.8 Hz, 2H), 8.27 (d, J = 8.8 Hz, 2H), 8.14 (d, J = 8.2 Hz, 1H), 7.97 (d, J = 8.0 Hz, 1H), 7.56 (t, J = 8.1 Hz, 1H), 7.47 (t, J = 7.6 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.85, 154.08, 149.00, 139.17, 135.5, 128.24, 126.94, 126.24, 124.34, 123.93, 121.86 ppm.



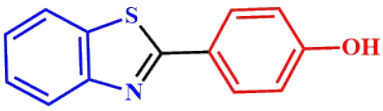
4-(benzo[d]thiazol-2-yl)benzonitrile (3g). White solid (44.9 mg, 95%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.21 (d, J = 8.5 Hz, 2H), 8.12 (d, J = 8.1 Hz, 1H), 7.95 (d, J = 7.9 Hz, 1H), 7.79 (d, J = 8.5 Hz, 2H), 7.55 (t, J = 8.3 Hz, 1H), 7.46 (t, J = 8.1 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 165.35, 154.03, 137.51, 135.32, 132.80, 127.95, 126.84, 126.09, 123.82, 121.82, 118.30, 114.14 ppm.



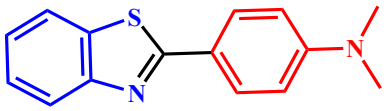
2-(4-methoxyphenyl)benzo[d]thiazole (3h). White solid (43.4 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11–7.99 (m, 3H), 7.88 (d, J = 7.9 Hz, 1H), 7.47 (t, J = 8.2 Hz, 1H), 7.35 (t, J = 8.1 Hz, 1H), 7.00 (d, J = 8.8 Hz, 2H), 3.88 (s, 3H, OCH_3) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 167.86, 161.92, 154.23, 134.87, 129.12, 126.45, 126.21, 124.79, 122.83, 121.51, 55.48 (OCH_3)ppm.



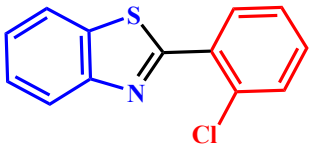
2-(*p*-tolyl)benzo[d]thiazole (3i). Yellow solid (41.4 mg, 92%) ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.06 (d, J = 8.2 Hz, 1H), 7.99 (d, J = 8.1 Hz, 2H), 7.89 (d, J = 7.9 Hz, 1H), 7.48 (t, J = 8.2 Hz, 1H), 7.37 (t, J = 8.1 Hz, 1H), 7.30 (d, J = 8.0 Hz, 2H), 2.43 (s, 3H, CH_3) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 168.26, 154.16, 141.45, 134.94, 130.95, 129.73, 127.49, 126.26, 125.01, 123.05, 121.58, 21.56 (CH_3)ppm.



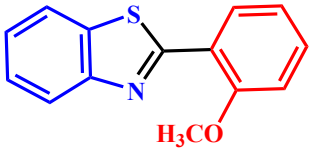
2-(4-hydroxyphenyl)benzo[d]thiazole (3j). Yellow solid (38.6 mg, 85%). ^{1}H NMR (400 MHz, DMSO-d_6): δ 10.25 (s, 1H), 8.09 (d, J = 7.9 Hz, 1H), 7.99 (d, J = 8.1 Hz, 1H), 7.94 (d, J = 8.6 Hz, 2H), 7.51 (t, J = 7.6 Hz, 1H), 7.39 (s, 1H), 6.96 (s, 2H) ppm. ^{13}C NMR (101 MHz, DMSO-d_6): δ 167.91, 160.99, 154.18, 134.56, 129.51, 126.89, 125.36, 124.49, 122.76, 122.58, 116.54 ppm.



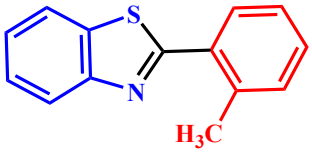
4-(benzo[d]thiazol-2-yl)-*N*,*N*-dimethylaniline (3k). Pale yellow solid (44.2 mg, 87%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.98 (t, J = 8.0 Hz, 3H), 7.84 (d, J = 7.9 Hz, 1H), 7.44 (t, J = 7.7 Hz, 1H), 7.31 (t, J = 7.6 Hz, 1H), 6.75 (d, J = 8.9 Hz, 1H), 3.06 (s, 6H, N(CH_3)$_2$) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 168.84, 154.35, 152.18, 134.50, 128.88, 126.00, 124.20, 122.25, 121.36, 111.70, 40.20 (N(CH_3)$_2$) ppm.



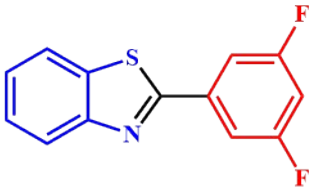
2-(2-chlorophenyl)benzo[d]thiazole (3l). White solid (39.2 mg, 79%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.30–8.18 (m, 1H), 8.15 (d, J = 8.2 Hz, 1H), 7.95 (d, J = 8.0 Hz, 1H), 7.53 (t, J = 7.6 Hz, 2H), 7.47–7.35 (m, 3H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.17, 152.54, 136.14, 132.74, 132.31, 131.78, 131.14, 130.82, 127.11, 126.30, 125.45, 123.49, 121.40 ppm.



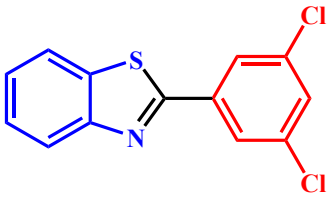
2-(2-methoxyphenyl)benzo[d]thiazole (3m).White solid (41.9 mg, 87%).^{1}H NMR (400 MHz, $CDCl_3$): δ 8.53 (d, J = 9.5 Hz, 1H), 8.09 (d, J = 8.2 Hz, 1H), 7.92 (d, J = 7.9 Hz, 1H), 7.56−7.42 (m, 2H), 7.36 (t, J = 8.0 Hz, 1H), 7.13 (t, J = 7.6 Hz, 1H), 7.05 (d, J = 8.3 Hz, 1H), 4.04 (s, 3H, OCH_3) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.17, 157.24, 152.15, 136.12, 131.80, 129.55, 125.91, 124.60, 122.53, 122.29, 121.22, 121.18, 111.69, 55.72 (OCH_3) ppm.



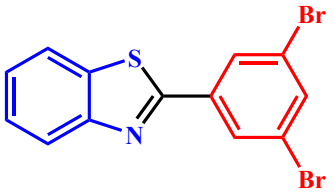
2-(*o*-tolyl)benzo[d]thiazole (3n). White solid (39.3 mg, 85%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11 (d, J = 8.2 Hz, 1H), 7.93 (d, J = 8.0 Hz, 1H), 7.76 (d, J = 7.6 Hz, 1H), 7.51 (t, J = 7.4 Hz, 1H), 7.41 (t, J = 7.6 Hz, 1H), 7.34 (dt, J = 14.8, 6.9 Hz, 3H), 2.66 (s, 3H, CH_3) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 168.01, 153.80, 137.26, 135.61, 133.10, 131.55, 130.55, 130.02, 126.14, 126.12, 125.10, 123.39, 121.38, 21.37 (CH_3) ppm.



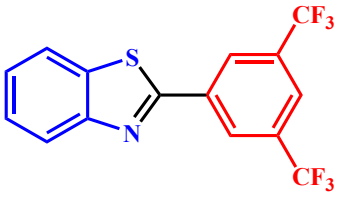
2-(3,5-difluorophenyl)benzo[d]thiazole (3o). White solid (44.5 mg, 90%).^{1}H NMR (400 MHz, $CDCl_3$): δ 8.20–8.01 (m, 3H), 7.90 (d, J = 7.9 Hz, 1H), 7.50 (t, J = 7.6 Hz, 1H), 7.39 (t, J = 7.6 Hz, 1H), 7.18 (t, J = 8.3 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.45, 153.83, 136.73, 136.05, 135.13, 129.05, 126.79, 125.95, 123.62 (d, J = 5.5 Hz), 121.79 ppm.



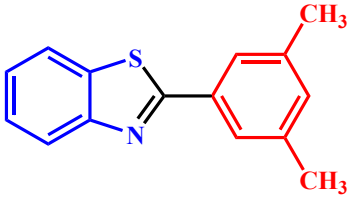
2-(3,5-dichlorophenyl)benzo[d]thiazole (3p).White solid (54.12 mg, 97%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.09 (d, J = 8.2 Hz, 1H), 7.98 (d, J = 1.9 Hz, 2H), 7.93 (d, J = 8.0 Hz, 1H), 7.59−7.51 (m, 1H), 7.47 (t, J = 1.9 Hz, 1H), 7.45−7.41 (m, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.69, 153.83, 136.27, 135.77, 135.11, 130.55, 126.76, 125.93, 125.76, 123.66, 121.78 ppm.



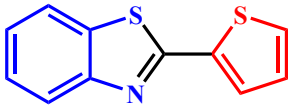
2-(3,5-dibromophenyl)benzo[d]thiazole (3q). White solid (68.9mg, 94%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.18 (s, 2H), 8.09 (d, J = 8.1 Hz, 1H), 7.93 (d, J = 7.9 Hz, 1H), 7.77 (t, J = 1.7 Hz, 1H), 7.54 (t, J = 7.1 Hz, 1H), 7.44 (t, J = 7.1 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.42, 153.80, 136.72, 136.05, 135.12, 129.04, 126.79, 125.95, 123.64, 123.59, 121.79 ppm.



2-(3,5-bis(trifluoromethyl)phenyl)benzo[d]thiazole (3r). White solid (66.6 mg, 96%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.54 (s, 2H), 8.14 (d, J = 8.1 Hz, 1H), 8.01–7.92 (m, 2H), 7.57 (t, J = 7.5 Hz, 1H), 7.48 (t, J = 7.5 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.12, 153.86, 135.63, 135.15, 133.11, 132.77, 132.44, 127.36 (d, J = 3.4 Hz), 127.00, 126.28, 124.35, 124.17–123.95 (m), 123.87, 121.89, 121.64 ppm.

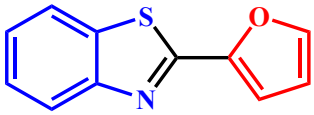


2-(3,5-dimethylphenyl)benzo[d]thiazole (3s). White solid (43.1mg, 90%).^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07 (d, J = 8.1 Hz, 1H), 7.90 (d, J = 8.0 Hz, 1H), 7.71 (s, 2H), 7.49 (t, J = 7.6 Hz, 1H), 7.38 (t, J = 7.5 Hz, 1H), 7.13 (s, 1H), 2.41 (s, 2 × 3H, CH_3) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 168.59, 154.11, 138.74, 135.00, 133.44 132.79, 126.27, 125.36, 125.07, 123.11, 121.60, 21.27 (CH_3) ppm.

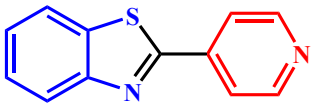


2-(thiophen-2-yl)benzo[d]thiazole (3t). White solid (41.7 mg, 96%).^{1}H NMR (400 MHz, $CDCl_3$): δ 8.03

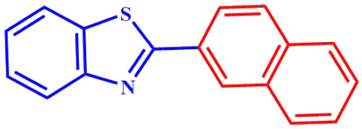
(d, *J* = 8.2 Hz, 1H), 7.86 (d, *J* = 8.4 Hz, 1H), 7.67 (d, *J* = 3.7 Hz, 1H), 7.49 (dd, *J* = 17.9, 7.1 Hz, 2H), 7.37 (t, *J* = 7.6 Hz, 1H), 7.17–7.12 (m, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 161.39, 153.69, 137.34, 134.69, 129.30, 128.62, 128.05, 126.43, 125.23, 122.98, 121.46 ppm.



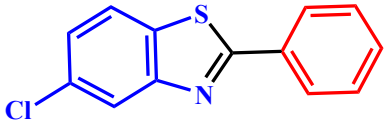
2-(furan-2-yl)benzo[d]thiazole (3u). White solid (36.2 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.05 (d, *J* = 8.1 Hz, 1H), 7.90 (d, *J* = 7.9 Hz, 1H), 7.61 (s, 1H), 7.50 (t, *J* = 8.2 Hz, 1H), 7.39 (t, *J* = 7.6 Hz, 1H), 7.20 (d, *J* = 3.5 Hz, 1H), 6.61 (s, 1H) ppm.^{13}C NMR (101 MHz, $CDCl_3$): *δ* 157.57, 153.75, 148.74, 144.72, 134.27, 126.49, 125.21, 123.13, 121.59, 112.55, 111.45 ppm.



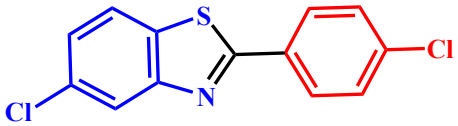
2-(pyridin-4-yl)benzo[d]thiazole (3v). White solid (36.0 mg, 85%). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.78 (d, *J* = 4.9 Hz, 2H), 8.13 (d, *J* = 8.2 Hz, 1H), 8.00–7.89 (m, 3H), 7.55 (t, *J* = 7.6 Hz, 1H), 7.46 (t, *J* = 7.6 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 165.10, 153.95, 150.78, 140.44, 135.20, 126.83, 126.21, 123.91, 121.88, 121.19 ppm.



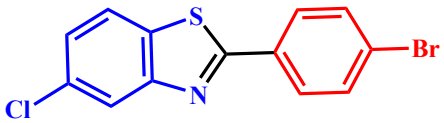
2-(naphthalen-2-yl)benzo[d]thiazole (3w). White solid (41.8 mg, 79%). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.55 (s, 1H), 8.21 (d, *J* = 8.5 Hz, 1H), 8.14 (d, *J* = 7.8 Hz, 1H), 8.04–7.83 (m, 4H), 7.66–7.48 (m, 3H), 7.39 (t, *J* = 7.5 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 168.12, 154.25, 135.16, 134.62, 133.19, 130.98, 128.85, 128.83, 127.89, 127.60, 127.47, 126.89, 126.41, 125.26, 124.45, 123.26, 121.67 ppm.



5-chloro-2-phenylbenzo[d]thiazole (4a). White solid (45.6 mg, 95%). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.06 (dd, *J* = 6.8, 3.3 Hz, 3H), 7.79 (d, *J* = 8.5 Hz, 1H), 7.55–7.45 (m, 3H), 7.35 (dd, *J* = 8.5, 1.9 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 169.93, 154.98, 133.31, 133.24, 132.32, 131.36, 129.11, 127.61, 125.66, 123.03, 122.32 ppm.

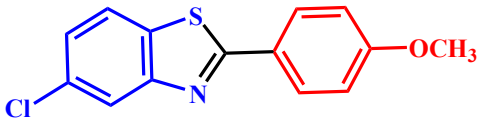


5-chloro-2-(4-chlorophenyl)benzo[d]thiazole (4b). White solid (47.4 mg, 85%). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.11–7.93 (m,3H), 7.81 (d, *J* = 8.5 Hz, 1H), 7.47 (d, *J* = 8.5 Hz, 2H), 7.37 (d, *J* = 8.5 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 168.42, 154.86, 137.44, 133.26, 132.49, 131.68, 129.34, 128.72, 125.86, 123.07, 122.32 ppm.

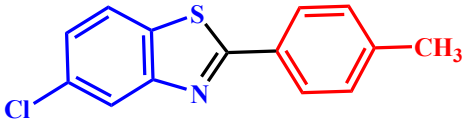


2-(4-bromophenyl)-5-chlorobenzo[d]thiazole (4c). White solid (52.3 mg, 81%). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.05 (s, 1H), 7.95 (d, *J* = 8.4 Hz, 2H), 7.82 (d, *J* = 8.5 Hz, 1H), 7.64 (d, *J* = 8.3 Hz, 2H), 7.38 (d, *J* = 10.5 Hz, 1H) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 168.54, 154.90, 133.27, 132.53, 132.33, 132.16, 128.94,

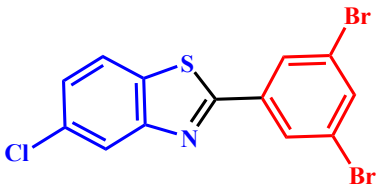
125.93, 125.88, 123.11, 122.36 ppm.



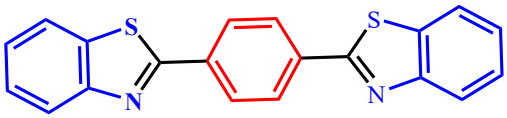
5-chloro-2-(4-methoxyphenyl)benzo[d]thiazole (4d). White solid (47.9 mg, 87%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.00 (d, J = 8.5 Hz, 3H), 7.76 (d, J = 8.5 Hz, 1H), 7.32 (d, J = 8.5 Hz, 1H), 6.99 (d, J = 8.7 Hz, 2H), 3.88 (s, 3H, OCH_3) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 169.70, 162.19, 155.08, 133.10, 132.15, 129.19, 126.01, 125.17, 122.60, 122.17, 114.42, 55.49 (OCH_3) ppm.



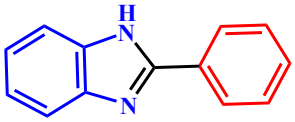
5-chloro-2-(p-tolyl)benzo[d]thiazole (4e). White solid (42.1 mg, 81%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.08 (s, 1H), 7.82 (d, J = 8.5 Hz, 1H), 7.75 (d, J = 7.6 Hz, 1H), 7.45–7.27 (m, 4H), 2.65 (s, 3H, CH_3) ppm. ^{13}C NMR (101 MHz, $CDCl_3$): δ 169.95, 154.64, 137.38, 133.79, 132.64, 132.15, 131.69, 130.44 (d, J = 20.7 Hz), 130.33, 126.21, 125.58, 123.17, 122.08, 21.45 (CH_3) ppm.



5-chloro-2-(3,5-dibromophenyl)benzo[d]thiazole (4f). White solid (74.6 mg, 93%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.12 (d, J = 1.6 Hz, 2H), 8.05 (d, J = 1.9 Hz, 1H), 7.82 (d, J = 8.6 Hz, 1H), 7.77 (s, 1H), 7.40 (d, J = 8.6 Hz, 1H) ppm.

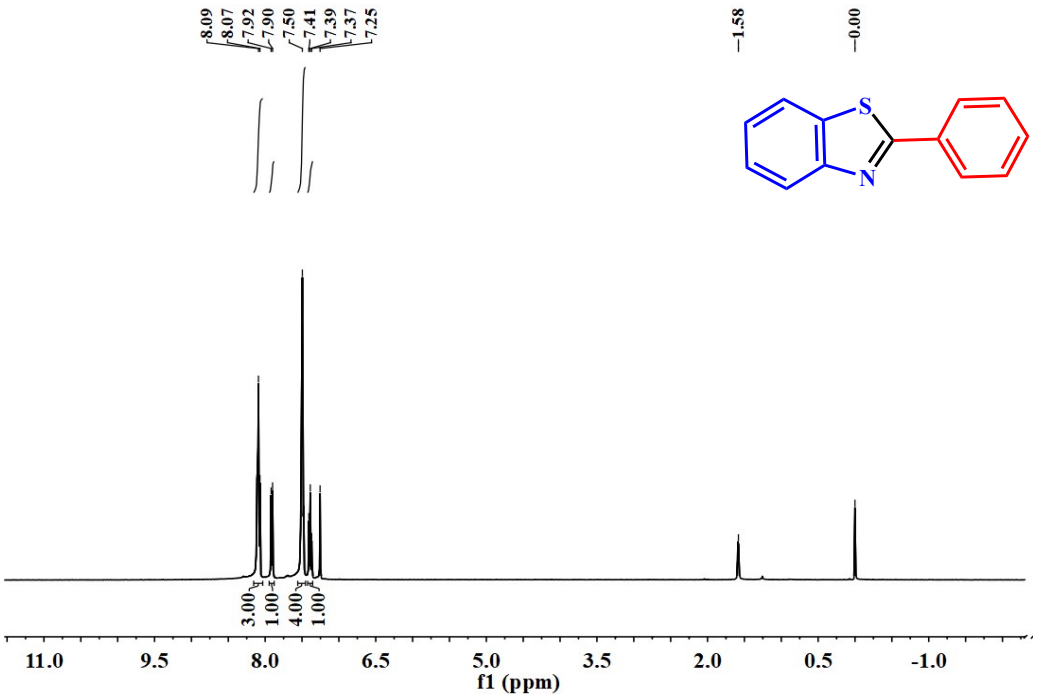


1,4-bis(benzo[d]thiazol-2-yl)benzene (4g). White solid (58.5 mg, 85%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.24 (s, 4H), 8.12 (d, J = 8.2 Hz, 2H), 7.95 (d, J = 8.0 Hz, 2H), 7.53 (t, J = 7.6 Hz, 2H), 7.43 (t, J = 7.5 Hz, 2H) ppm.

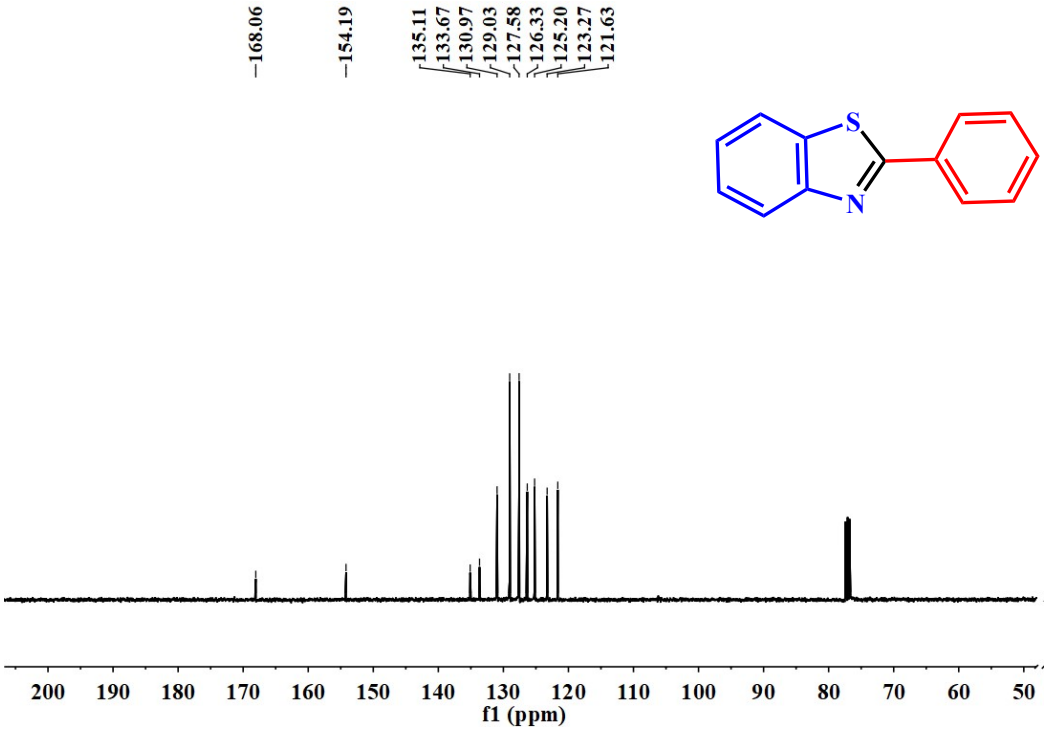


2-phenyl-1H-benzo[d]imidazole. White solid (38.8 mg, 85%). ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.93 (s, 1H), 8.19 (d, J = 7.2 Hz, 2H), 7.68 (d, J = 7.5 Hz, 1H), 7.62−7.42 (m, 4H), 7.34−7.13 (m, 2H) ppm. ^{13}C NMR (101 MHz, DMSO-d_6): δ 151.68, 144.42, 135.65, 130.61, 130.31, 129.42, 126.89, 122.98, 122.16, 119.25, 111.78 ppm.

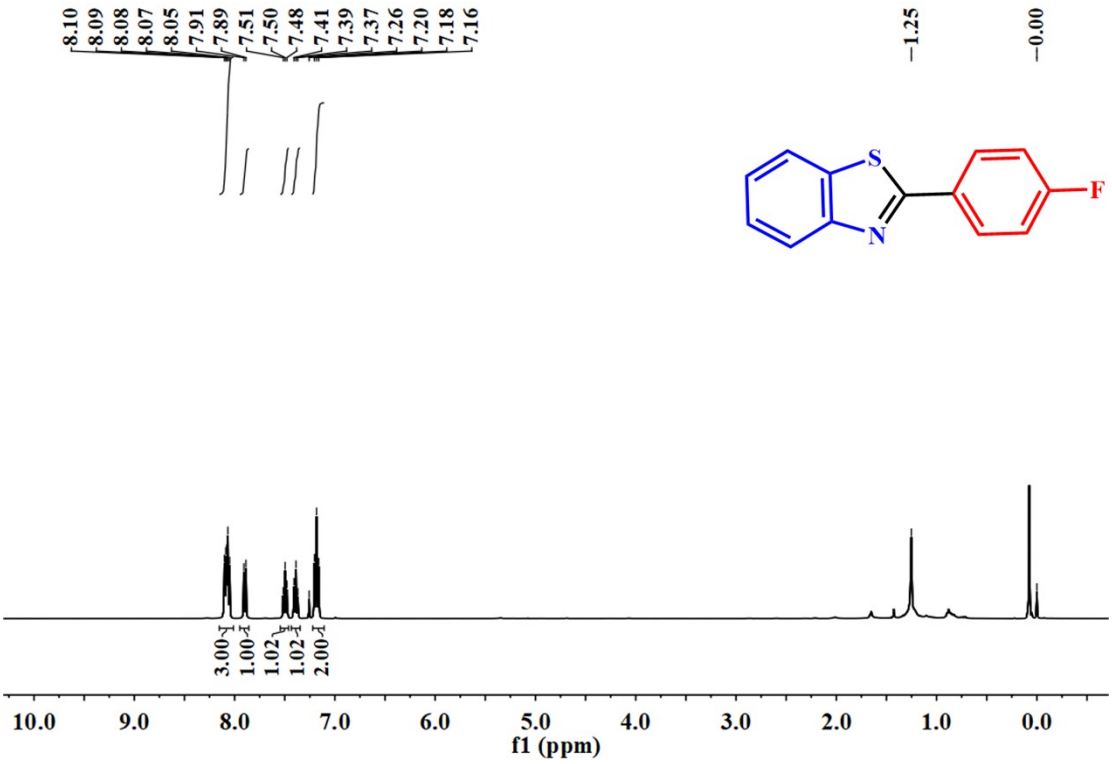
Section S7. ^{1}H and ^{13}C NMR spectra



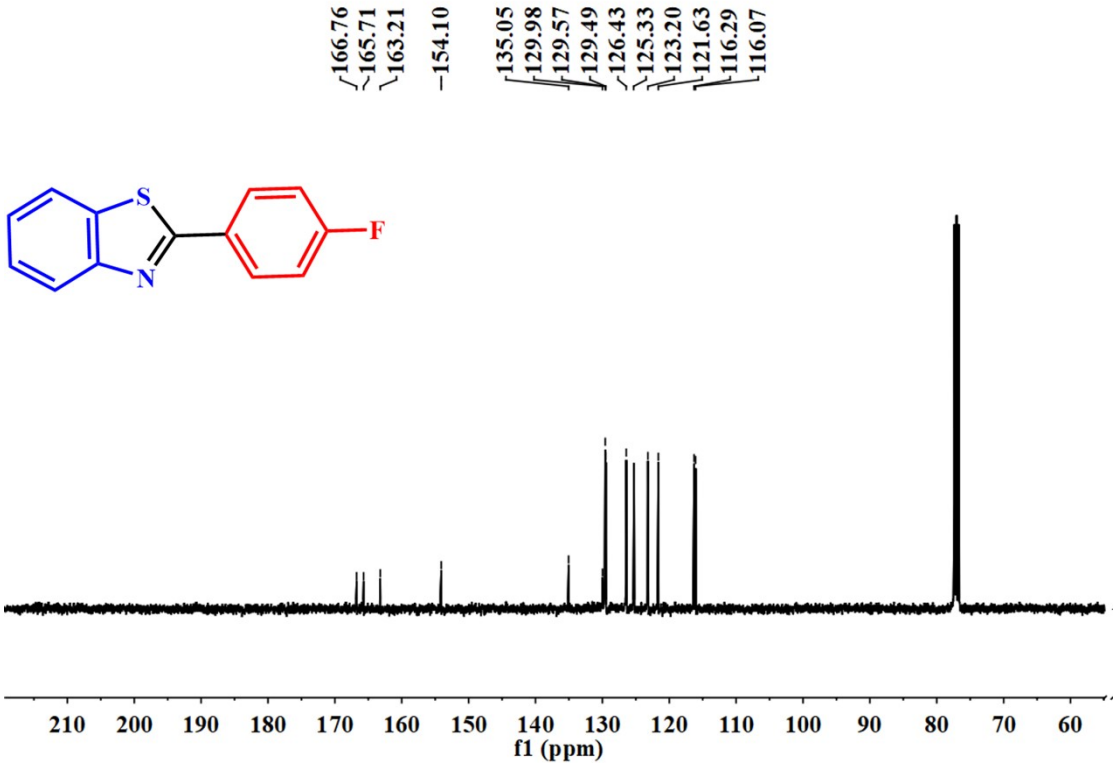
The ^{1}H-NMR spectrum of 2-phenylbenzo[d]thiazole (**3a**).



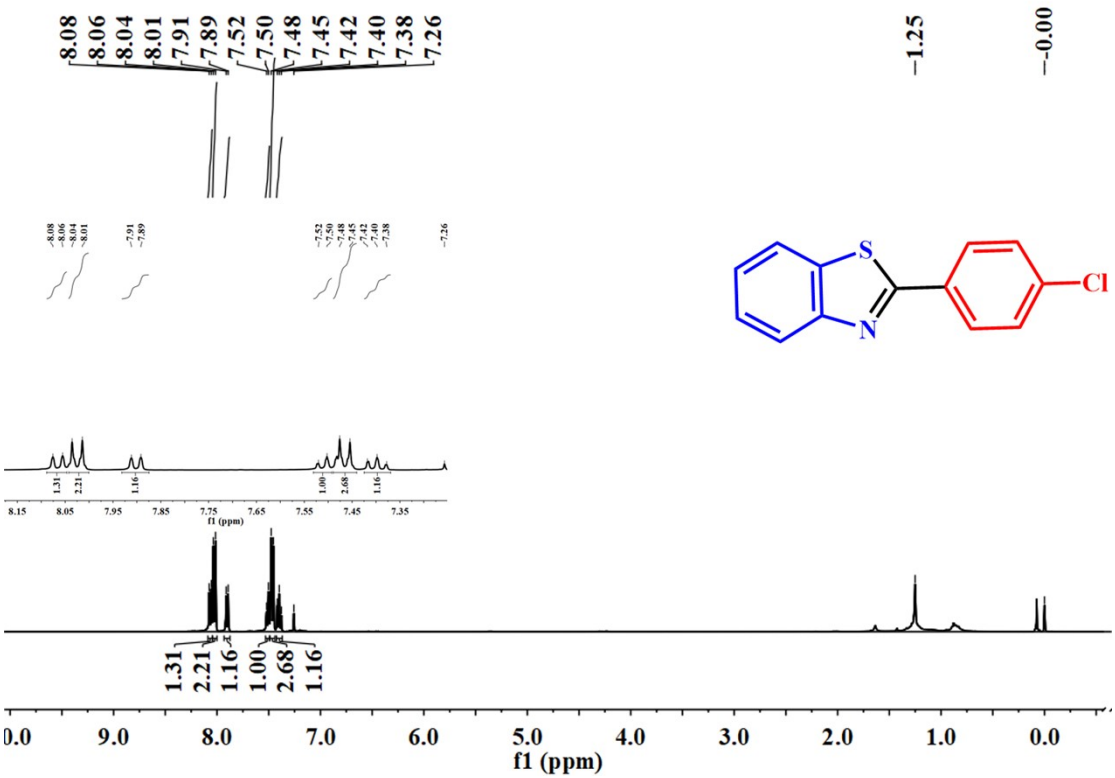
The ^{13}C NMR spectrum of 2-phenylbenzo[d]thiazole (**3a**).



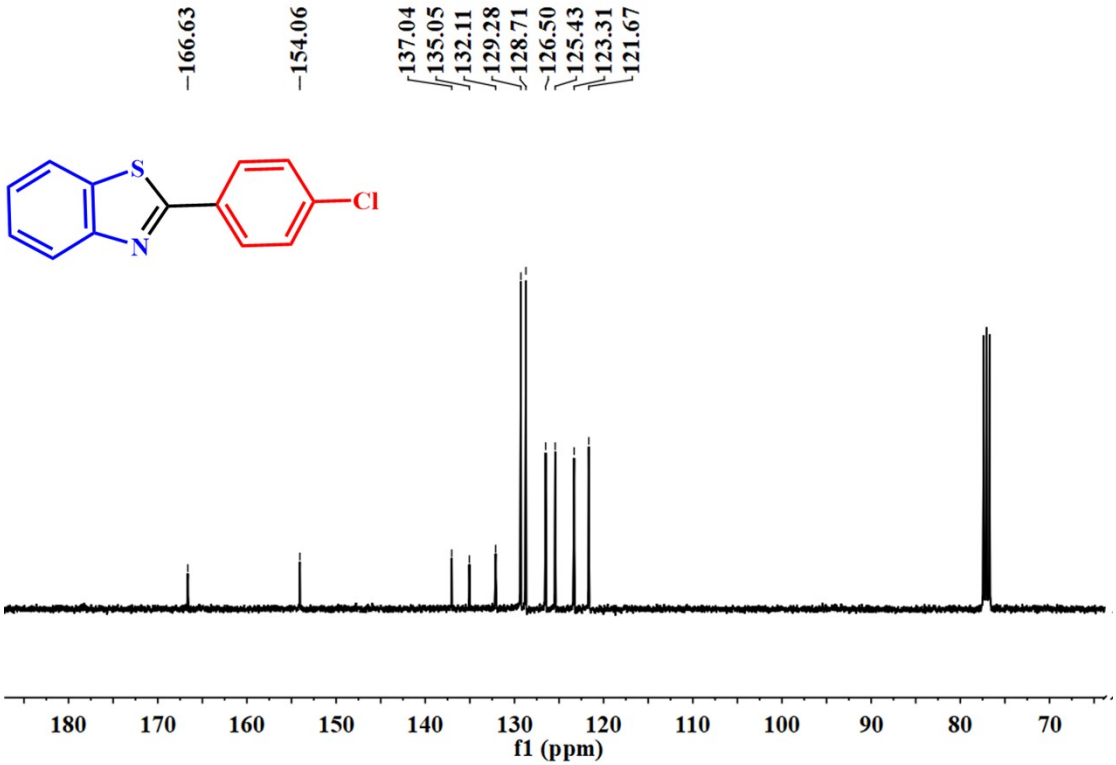
The ^{1}H-NMR spectrum of 2-(4-fluorophenyl)benzo[d]thiazole (**3b**).



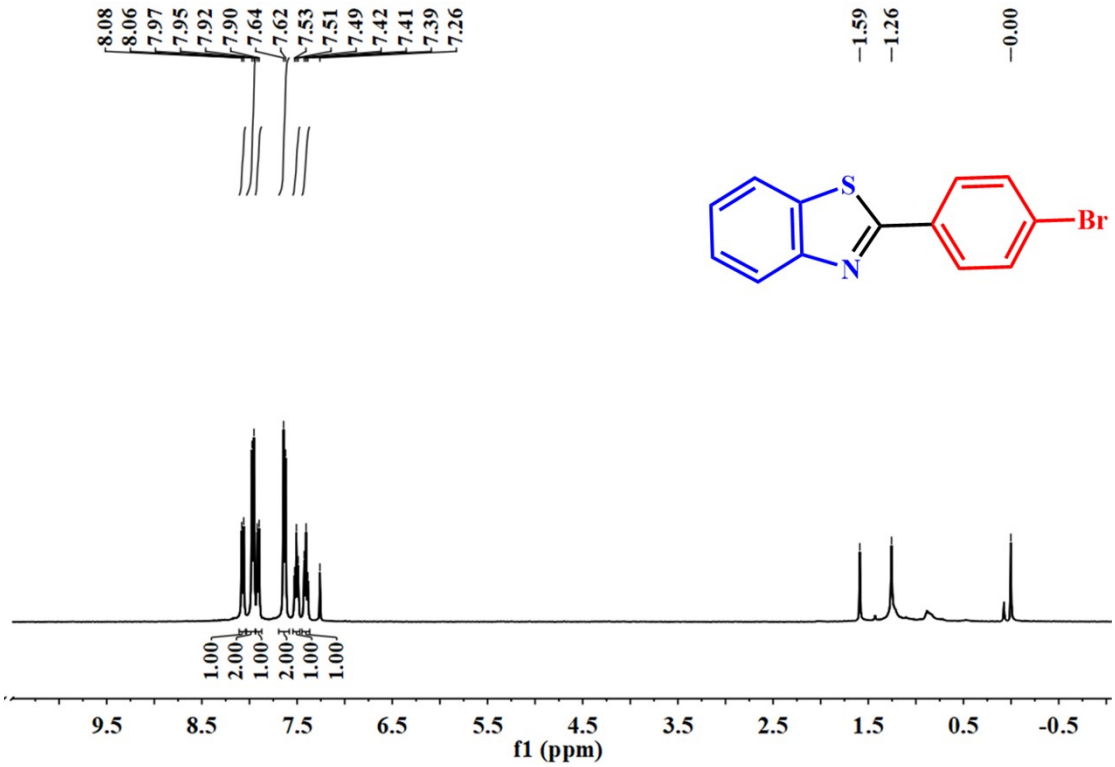
The ^{13}C-NMR spectrum of 2-(4-fluorophenyl)benzo[d]thiazole (**3b**).



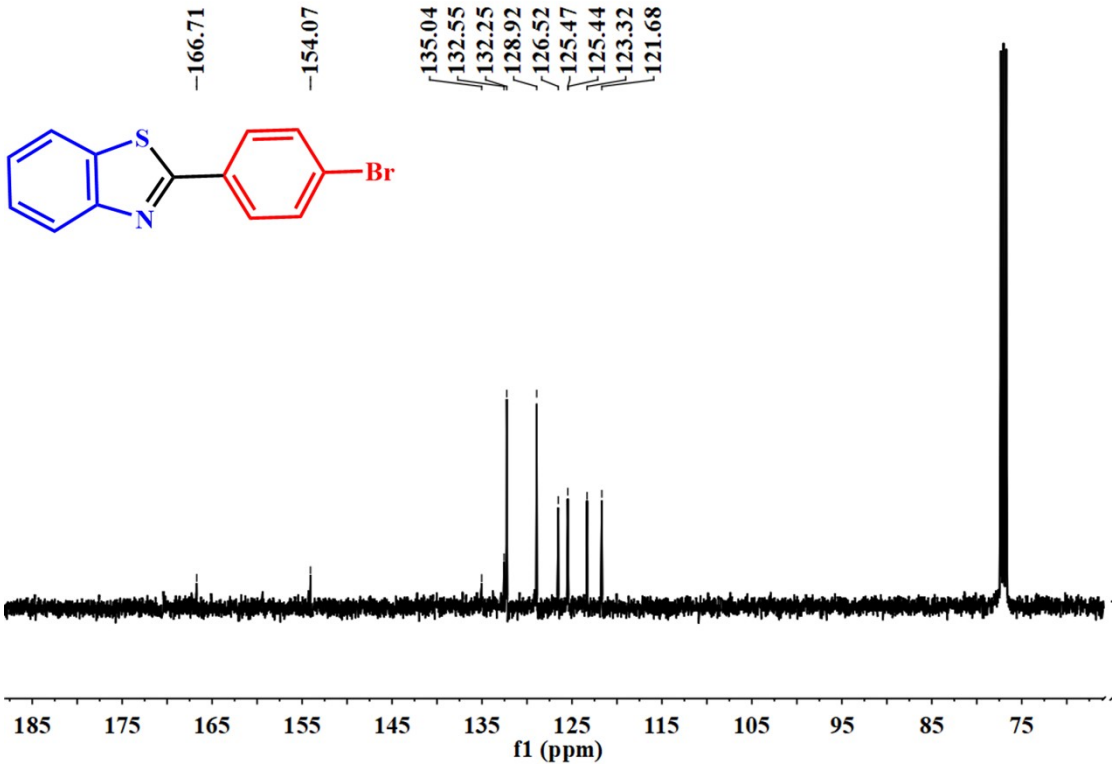
The ^{1}H-NMR spectrum of 2-(4-chlorophenyl)benzo[d]thiazole (**3c**).



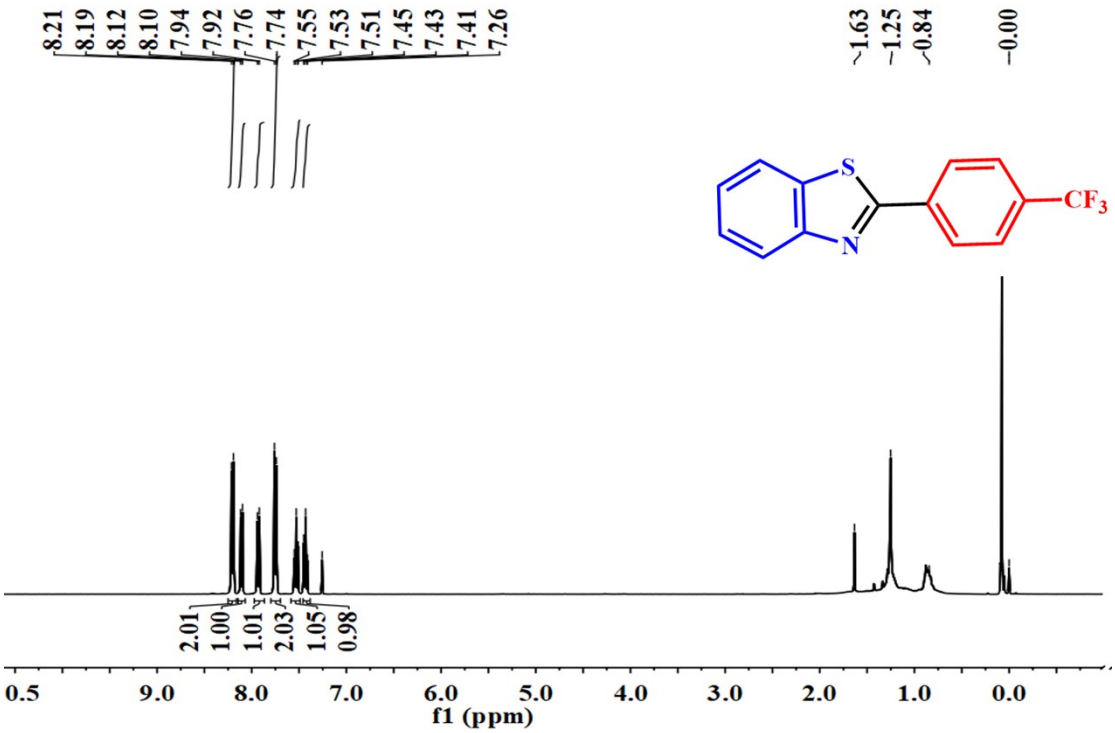
The ^{13}C-NMR spectrum of 2-(4-chlorophenyl)benzo[d]thiazole (**3c**).



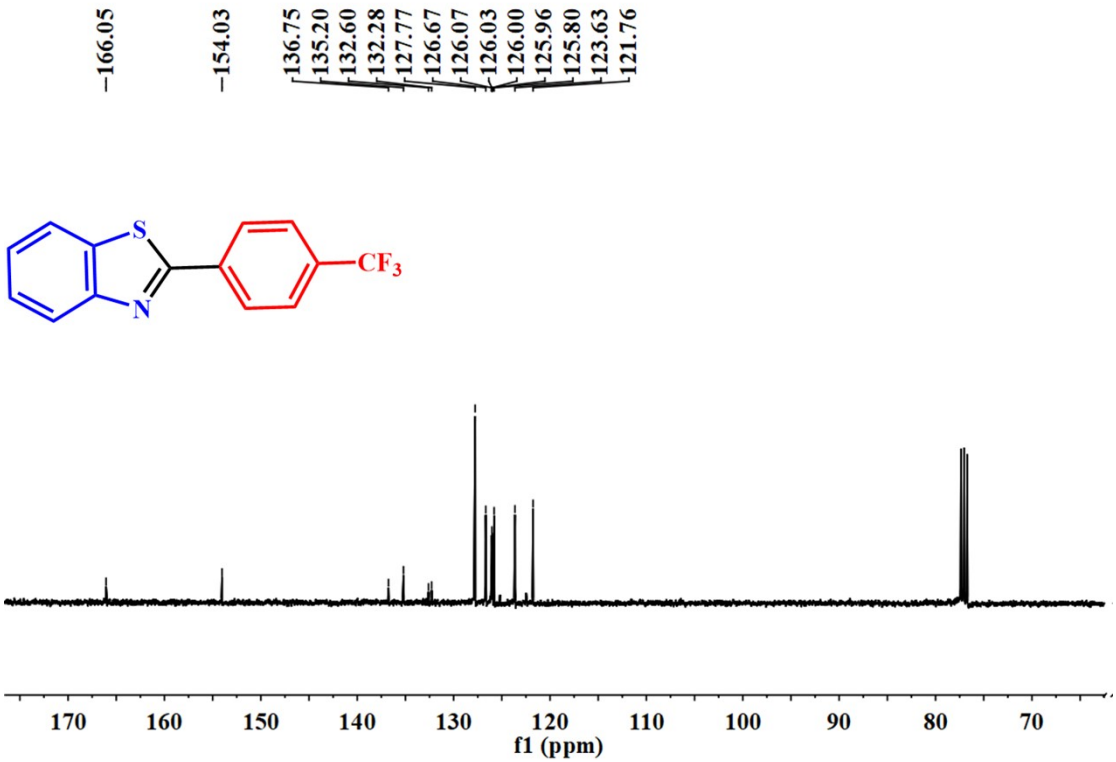
The ^{1}H-NMR spectrum of 2-(4-bromophenyl)benzo[d]thiazole (**3d**).



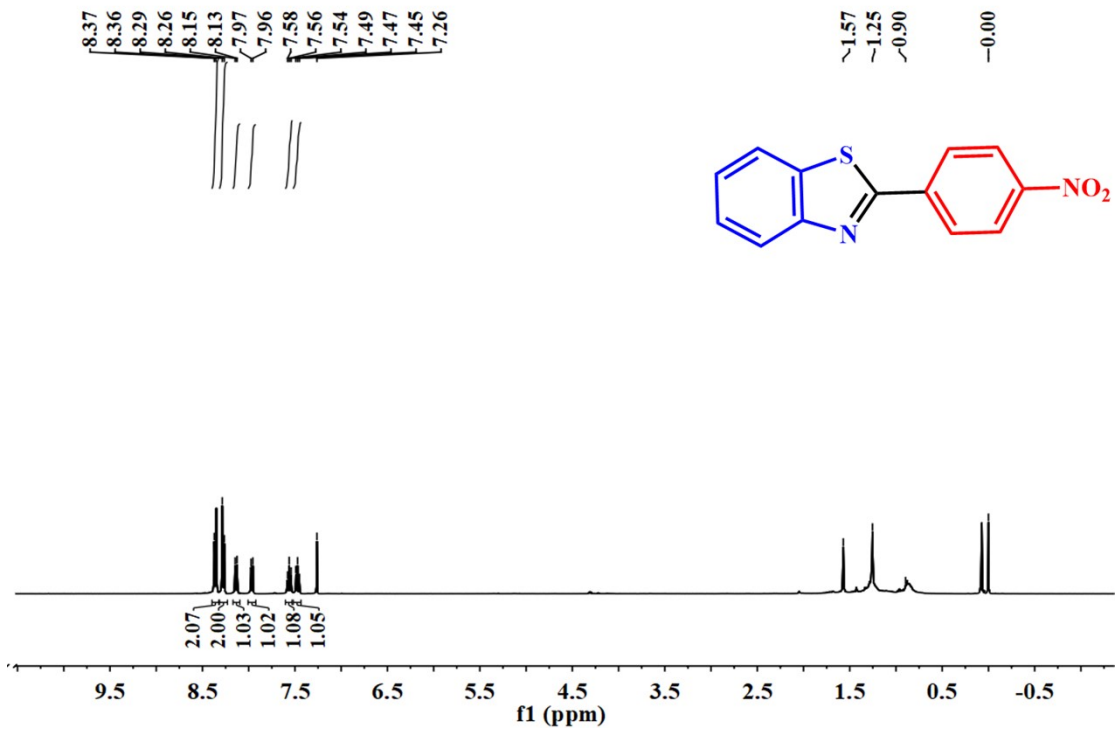
The ^{13}C-NMR spectrum of 2-(4-bromophenyl)benzo[d]thiazole (**3d**).



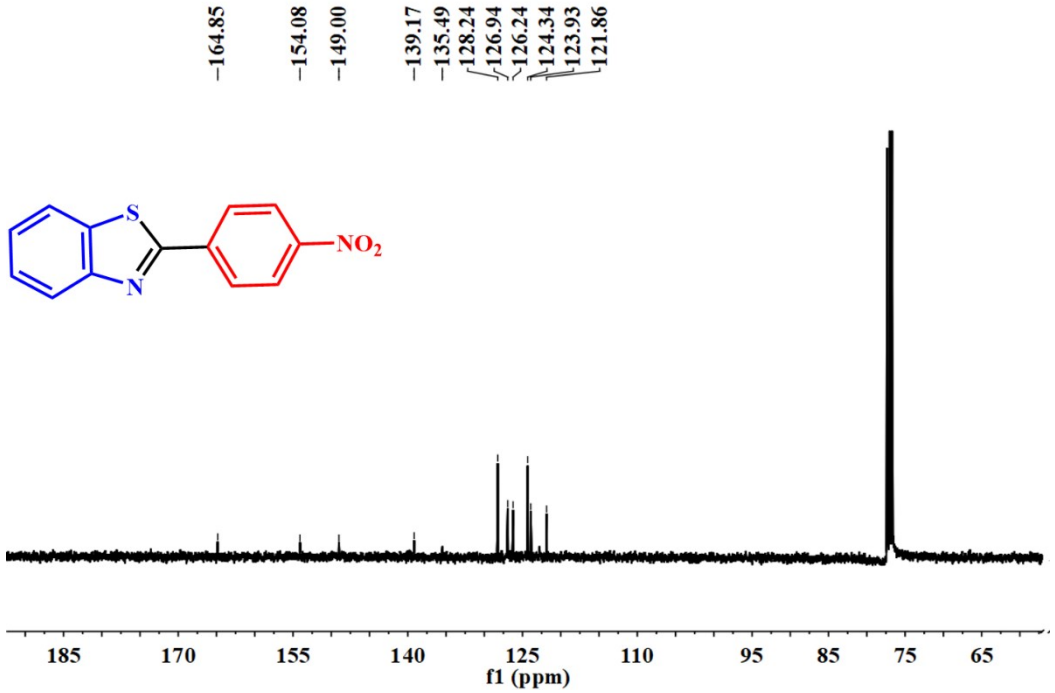
The ^{1}H-NMR spectrum of 2-(4-(trifluoromethyl)phenyl)benzo[d]thiazole (**3e**).



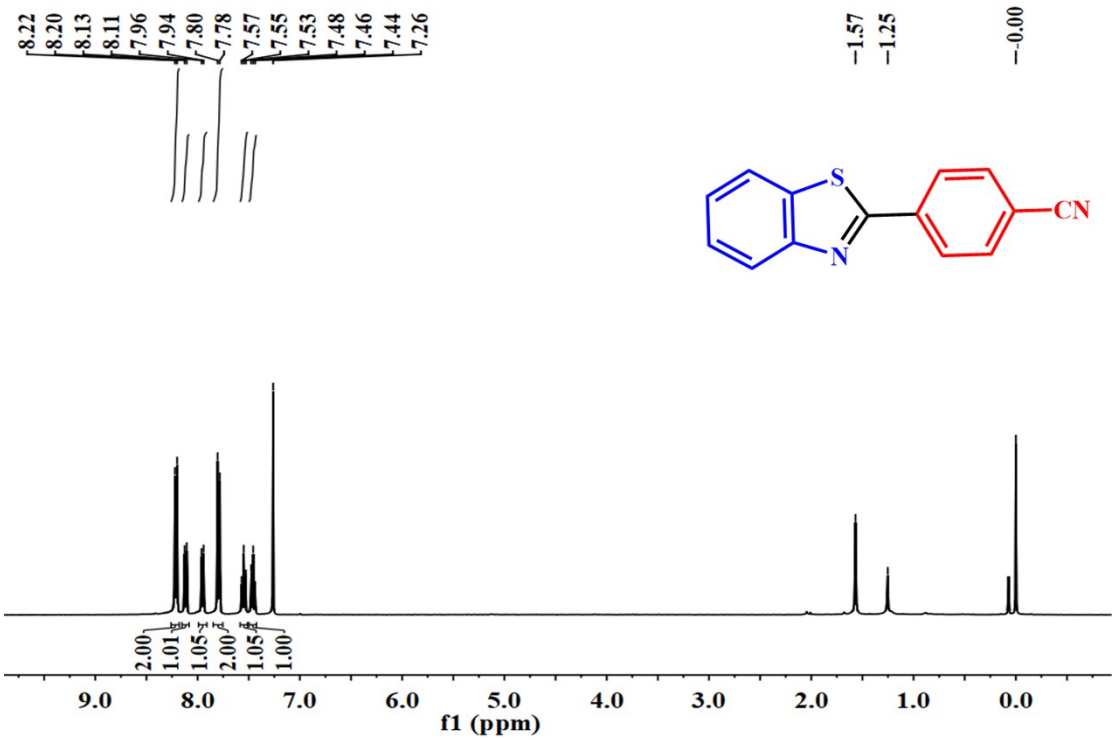
The ^{13}C-NMR spectrum of 2-(4-(trifluoromethyl)phenyl)benzo[d]thiazole (**3e**).



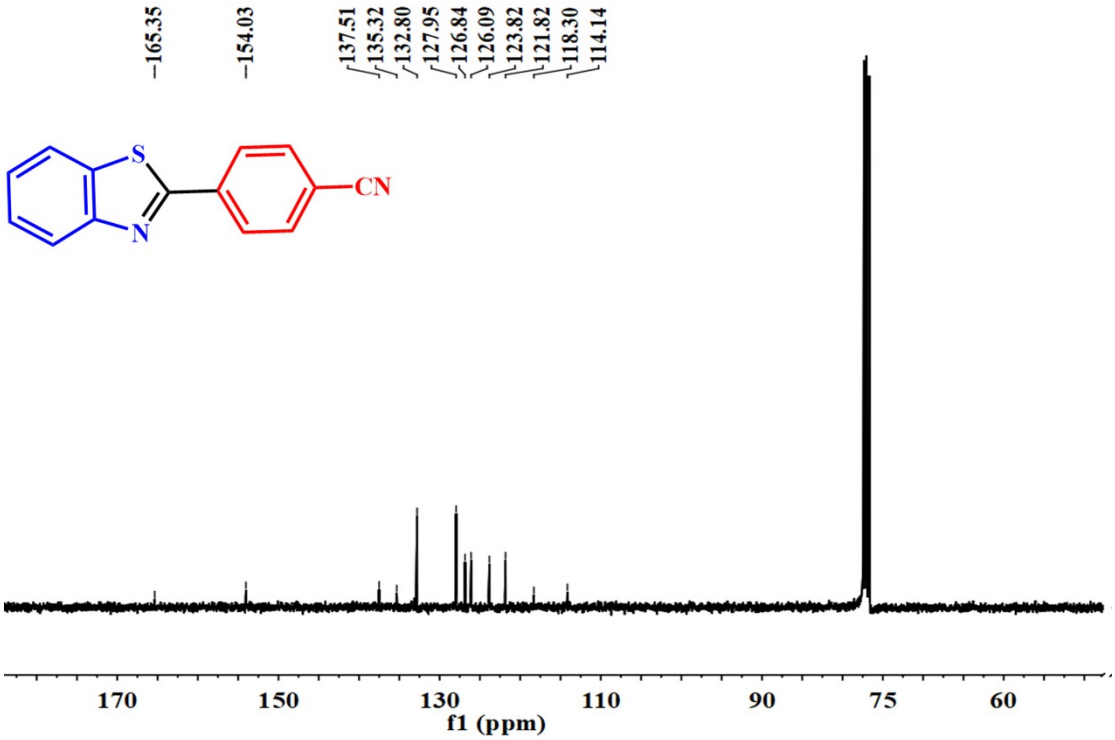
The ^{1}H-NMR spectrum of 2-(4-nitrophenyl)benzo[d]thiazole (**3f**).



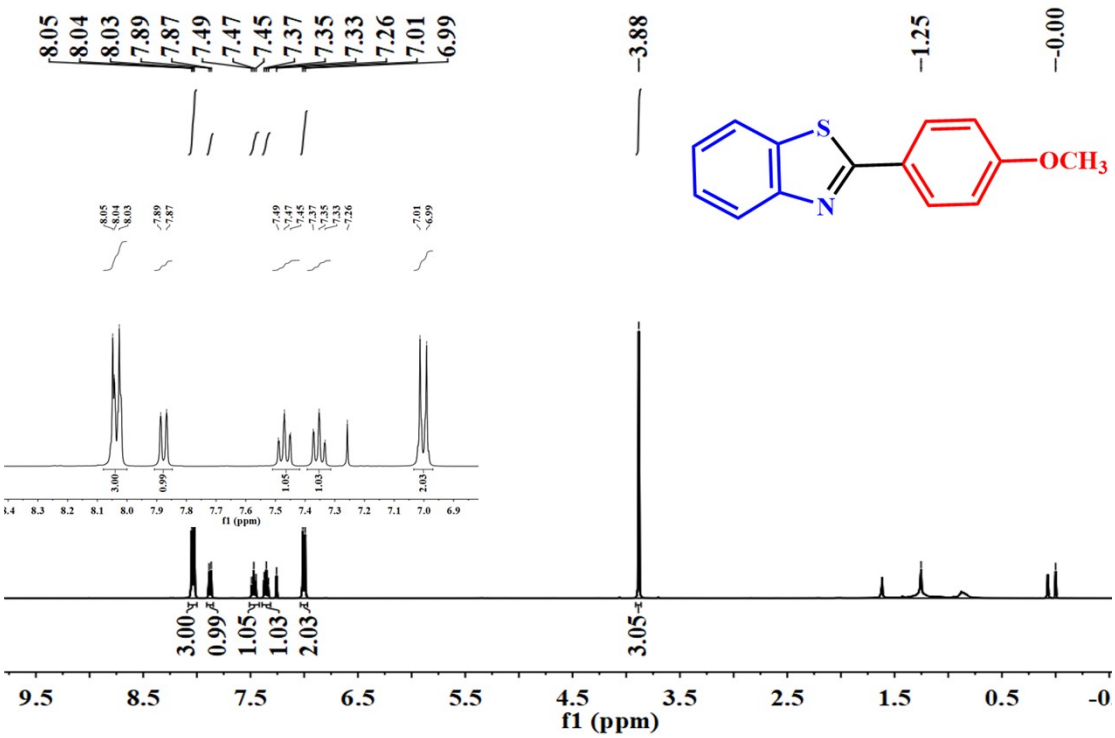
The ^{13}C-NMR spectrum of 2-(4-nitrophenyl)benzo[d]thiazole (**3f**).



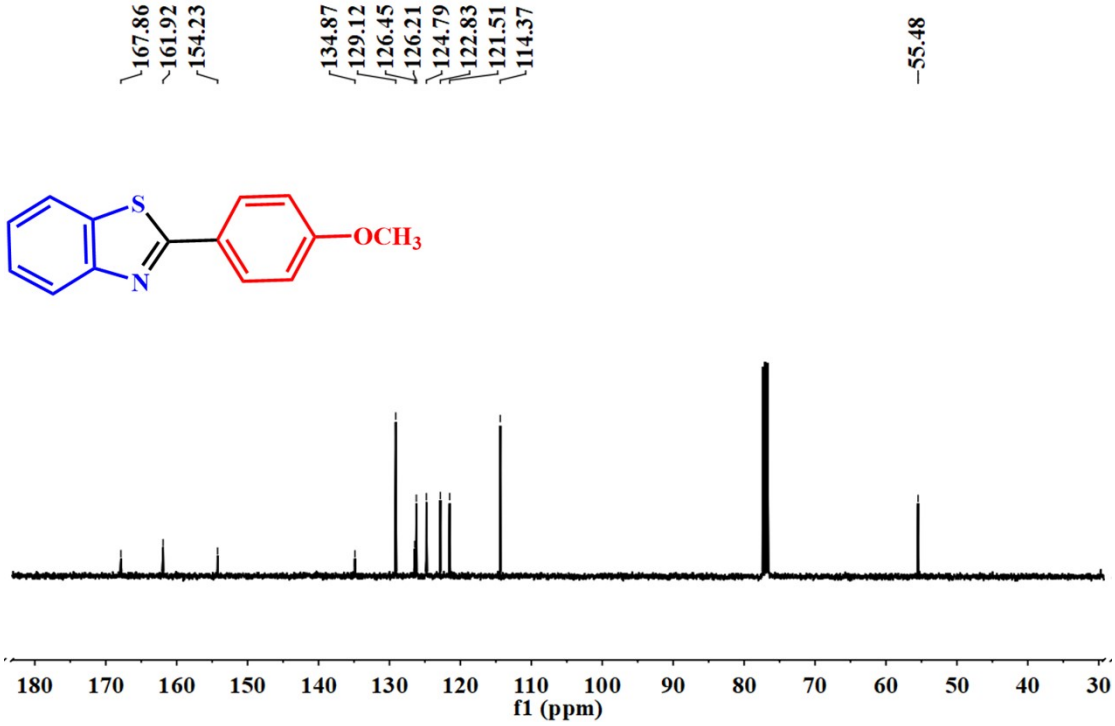
The ^{1}H-NMR spectrum of 4-(benzo[d]thiazol-2-yl)benzonitrile (**3g**).



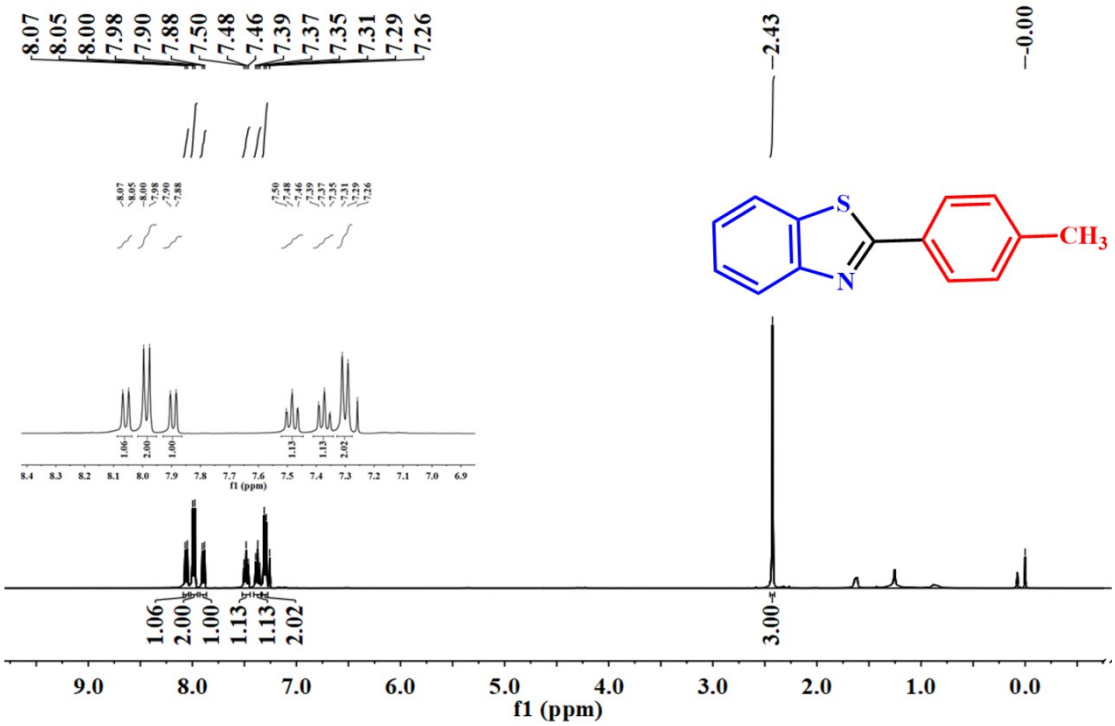
The ^{13}C-NMR spectrum of 4-(benzo[d]thiazol-2-yl)benzonitrile (**3g**).



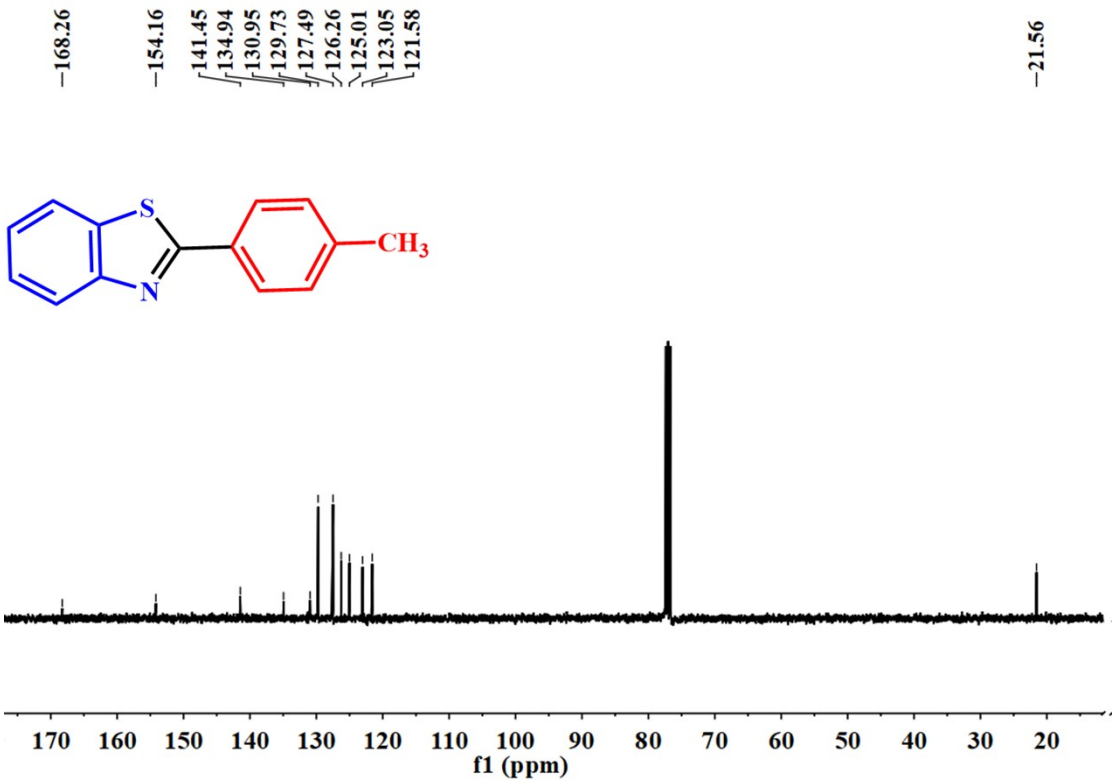
The ^{1}H-NMR spectrum of 2-(4-methoxyphenyl)benzo[d]thiazole (**3h**).



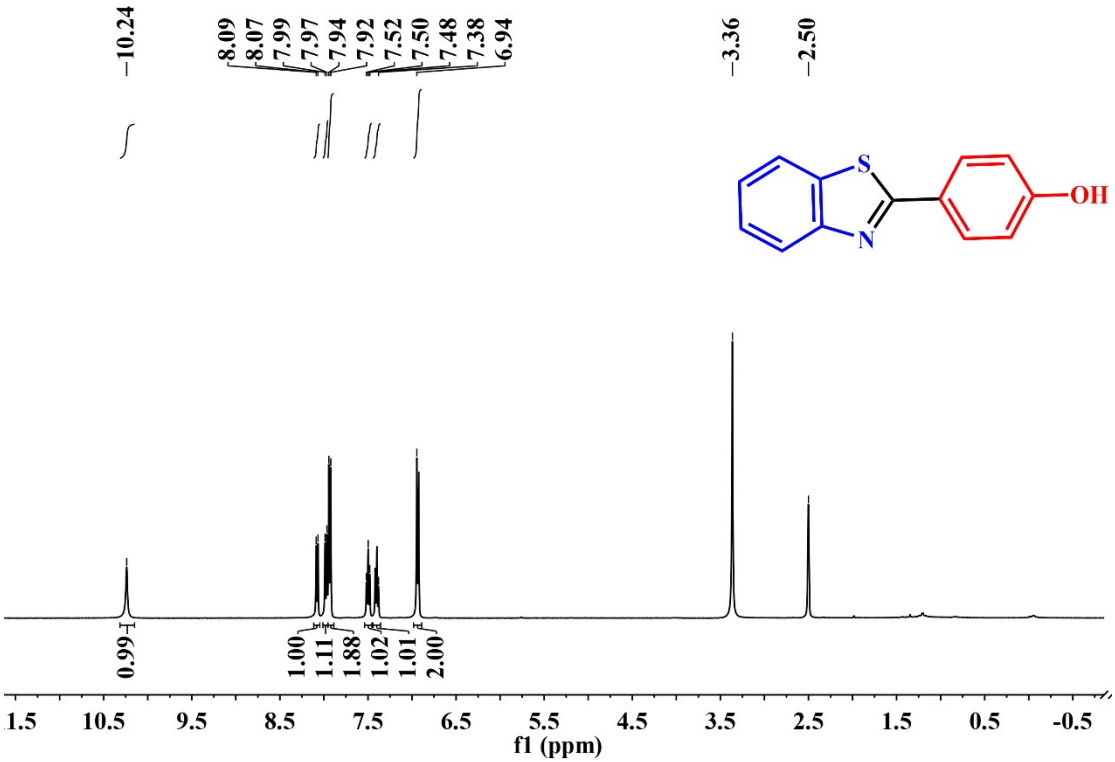
The ^{13}C-NMR spectrum of 2-(4-methoxyphenyl)benzo[d]thiazole (**3h**).



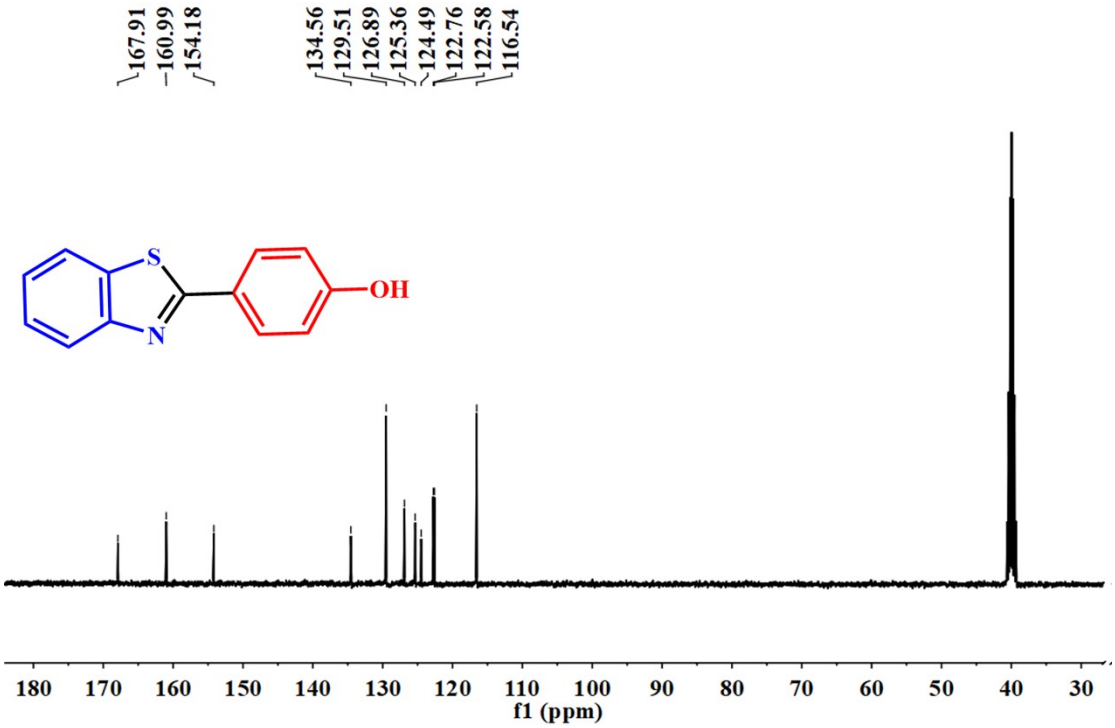
The ^{1}H-NMR spectrum of 2-(*p*-tolyl)benzo[d]thiazole (**3i**).



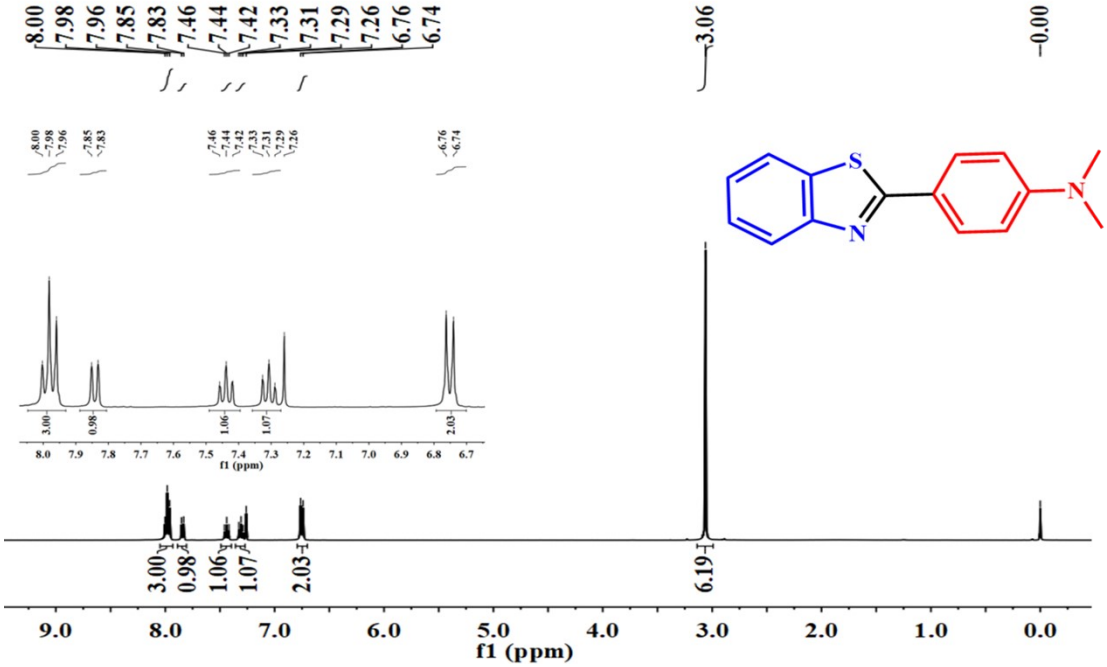
The ^{13}C-NMR spectrum of 2-(*p*-tolyl)benzo[d]thiazole (**3i**).



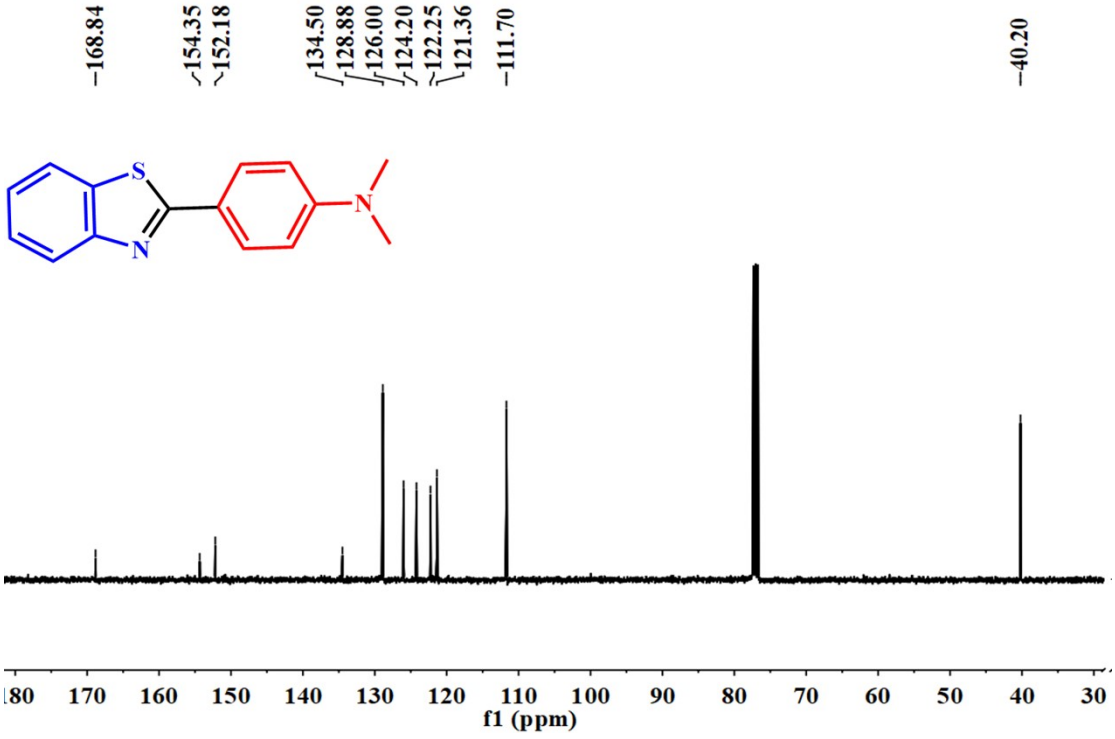
The ^{1}H-NMR spectrum of 2-4-(hydroxyphenyl)benzo[d]thiazol (**3j**).



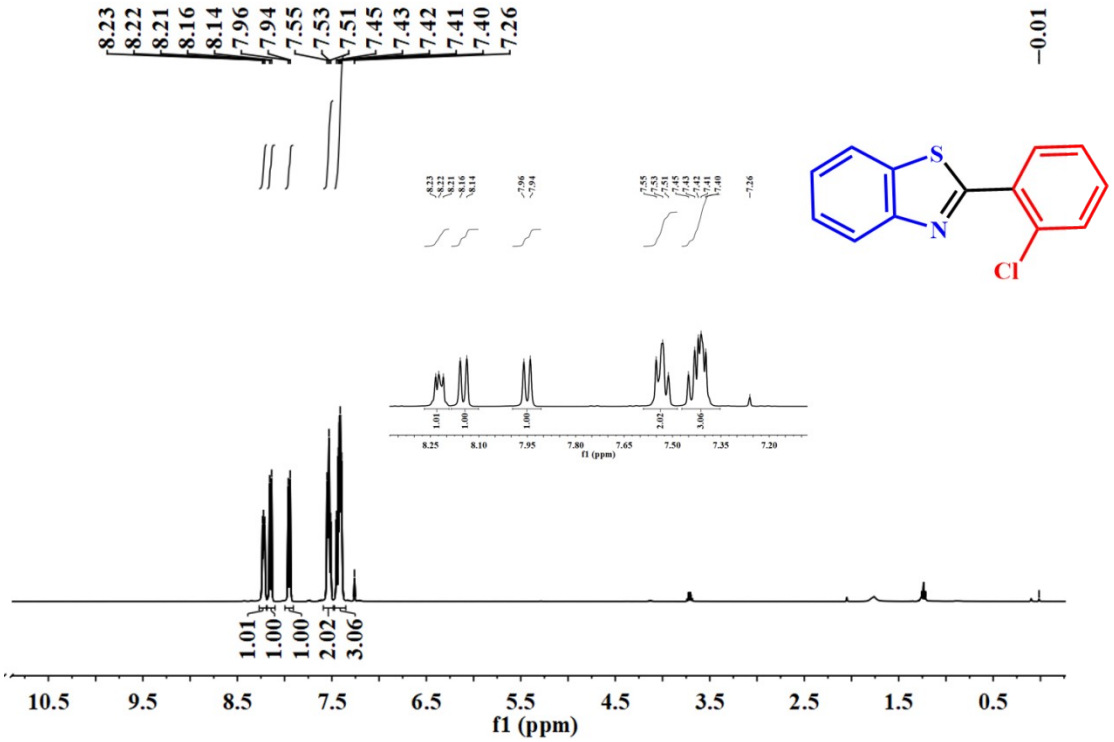
The ^{13}C-NMR spectrum of 2-4-(hydroxyphenyl)benzo[d]thiazol (**3j**).



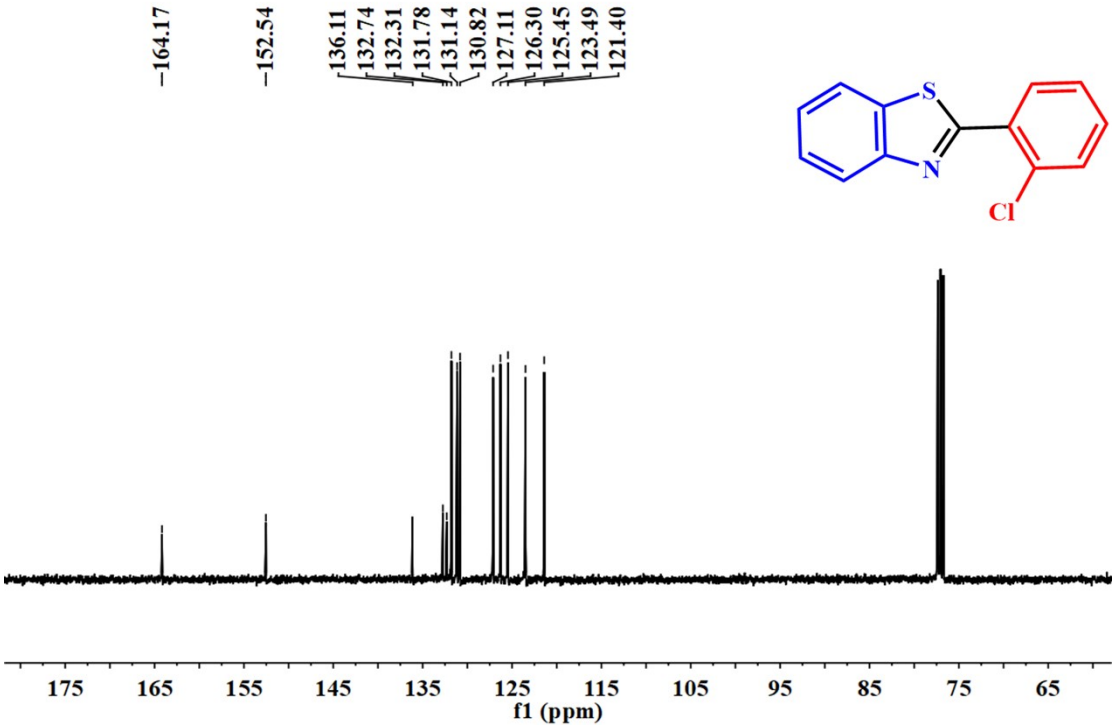
The ^{1}H-NMR spectrum of 4-(benzo[d]thiazol-2-yl)-*N*,*N*-dimethylaniline (**3k**).



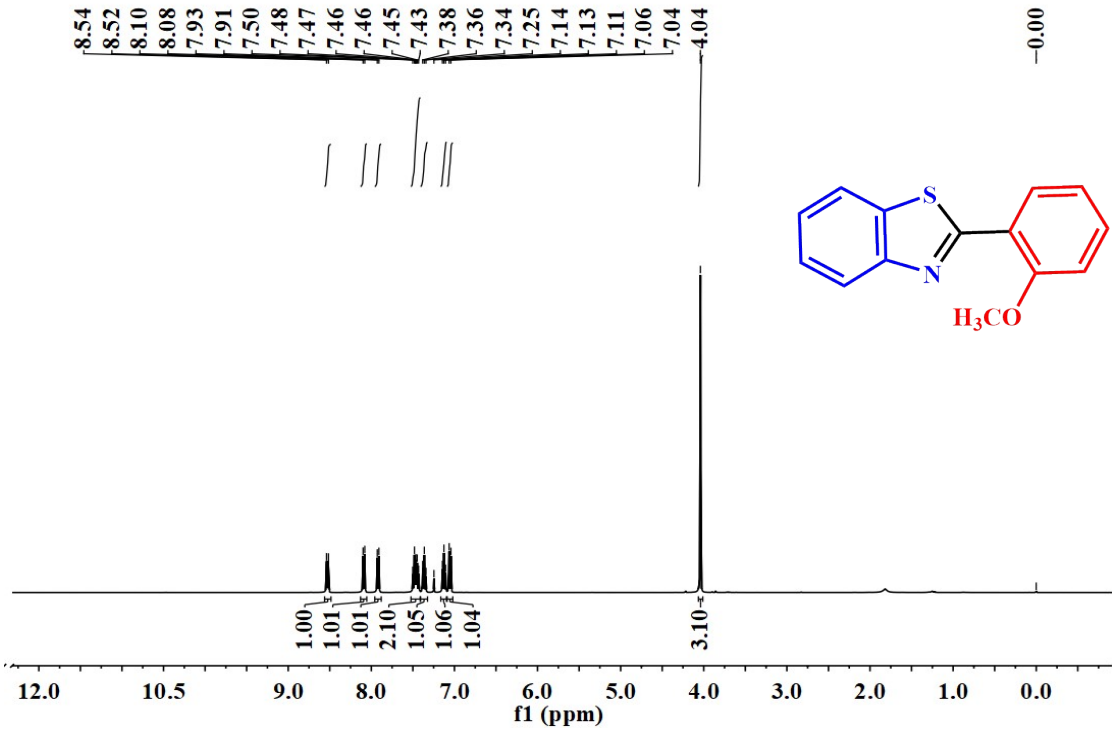
The ^{13}C-NMR spectrum of 4-(benzo[d]thiazol-2-yl)-*N*,*N*-dimethylaniline (**3k**).



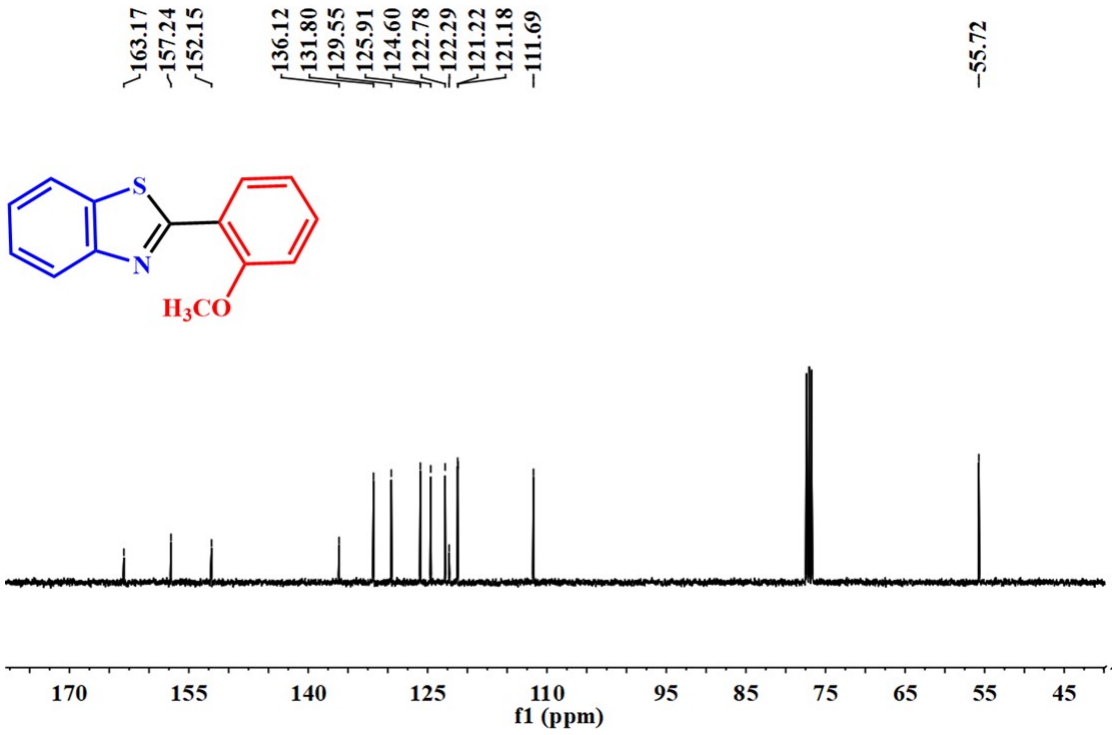
The ^{1}H-NMR spectrum of 2-(2-chlorophenyl)benzo[d]thiazole (**3l**).



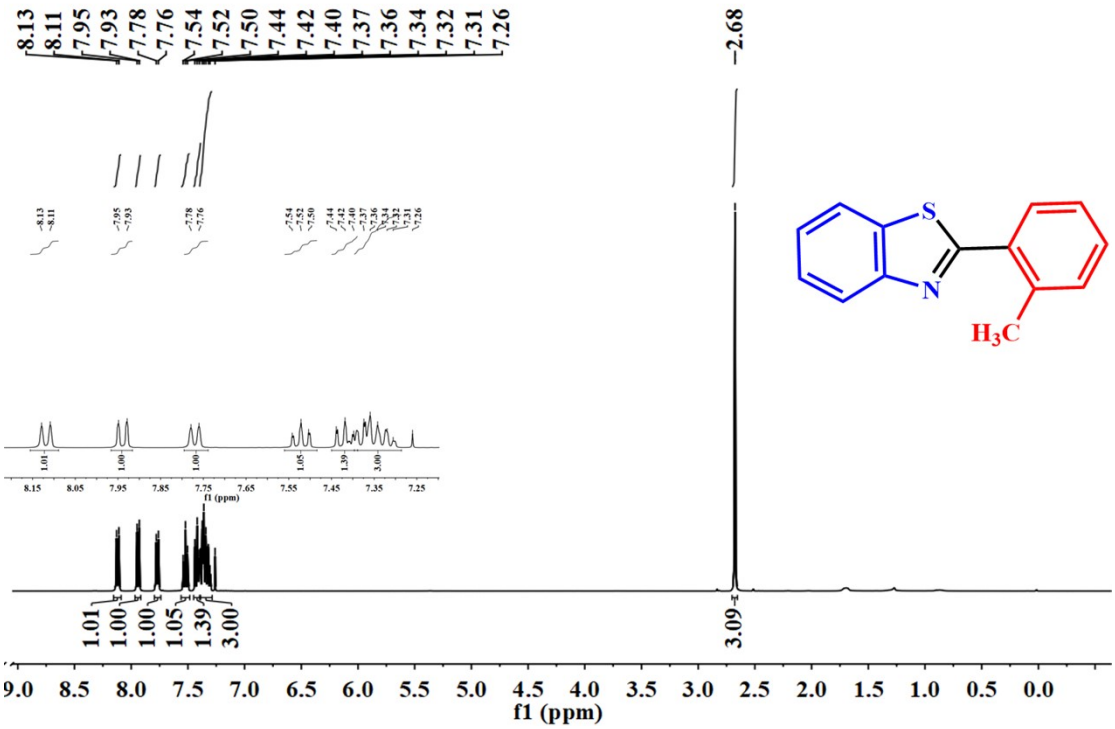
The ^{13}C-NMR spectrum of 2-(2-chlorophenyl)benzo[d]thiazole (**3l**).



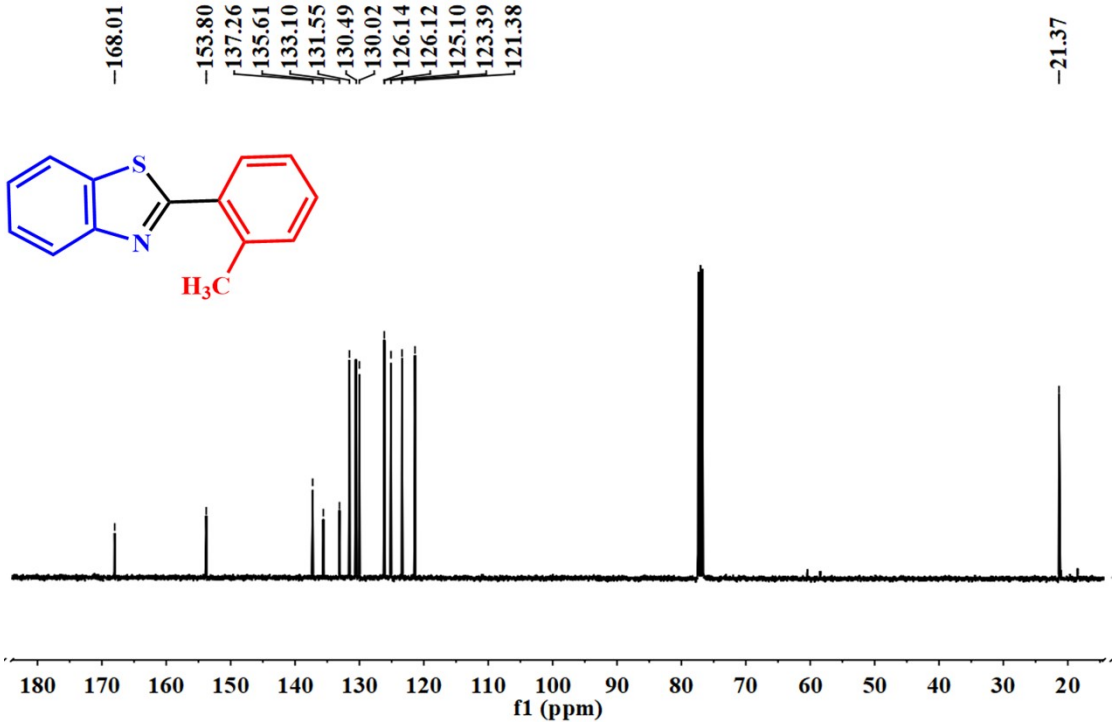
The ^{1}H-NMR spectrum of 2-(2-methoxyphenyl)benzo[d]thiazole **(3m)**.



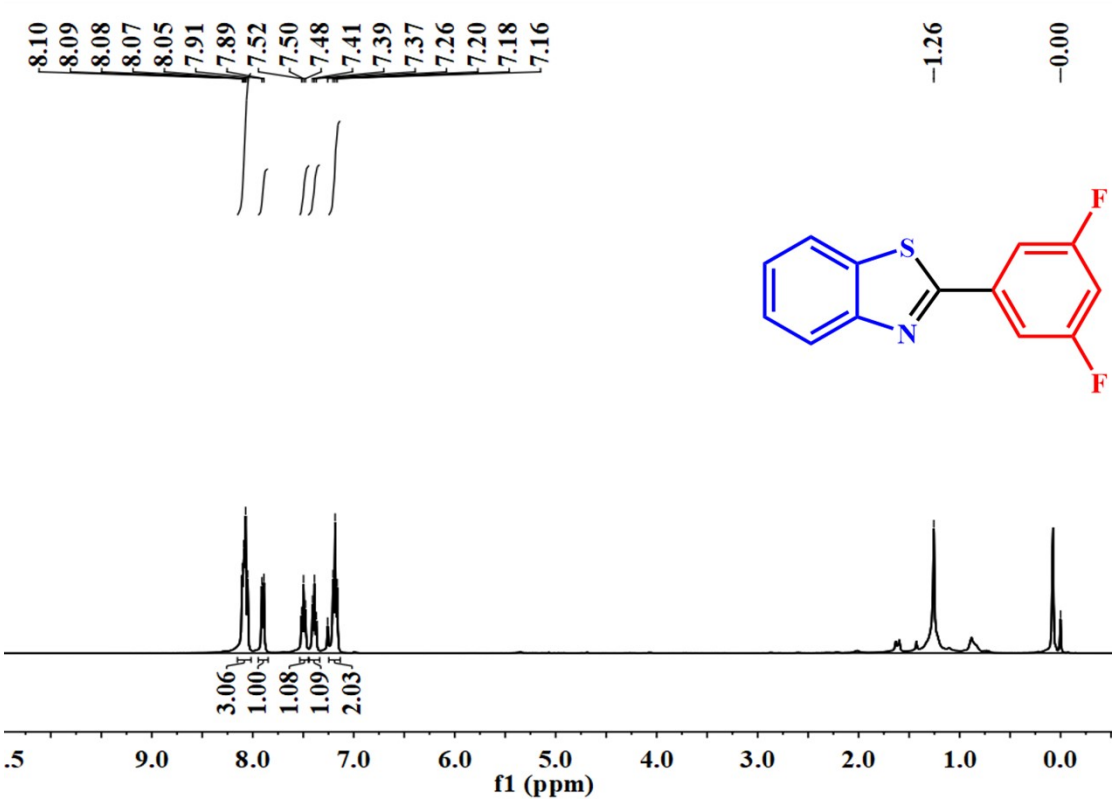
The ^{13}C-NMR spectrum of 2-(2-methoxyphenyl)benzo[d]thiazole (**3m**).



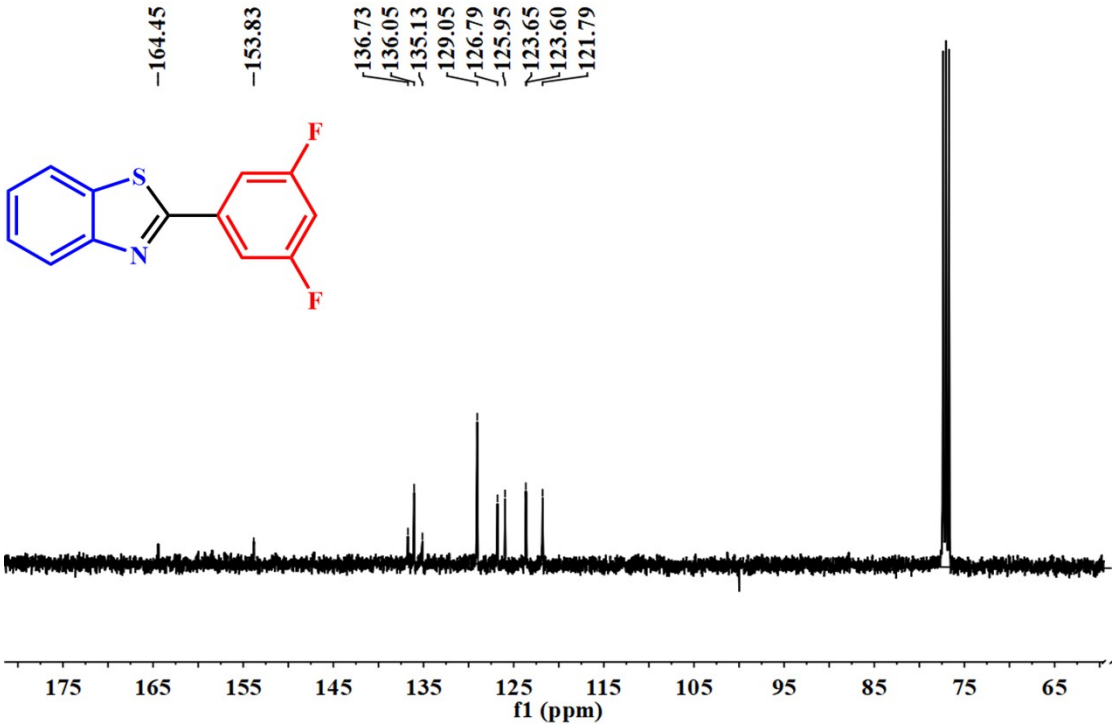
The ^{1}H-NMR spectrum of 2-(*o*-tolyl)benzo[d]thiazole (**3n**)**.**



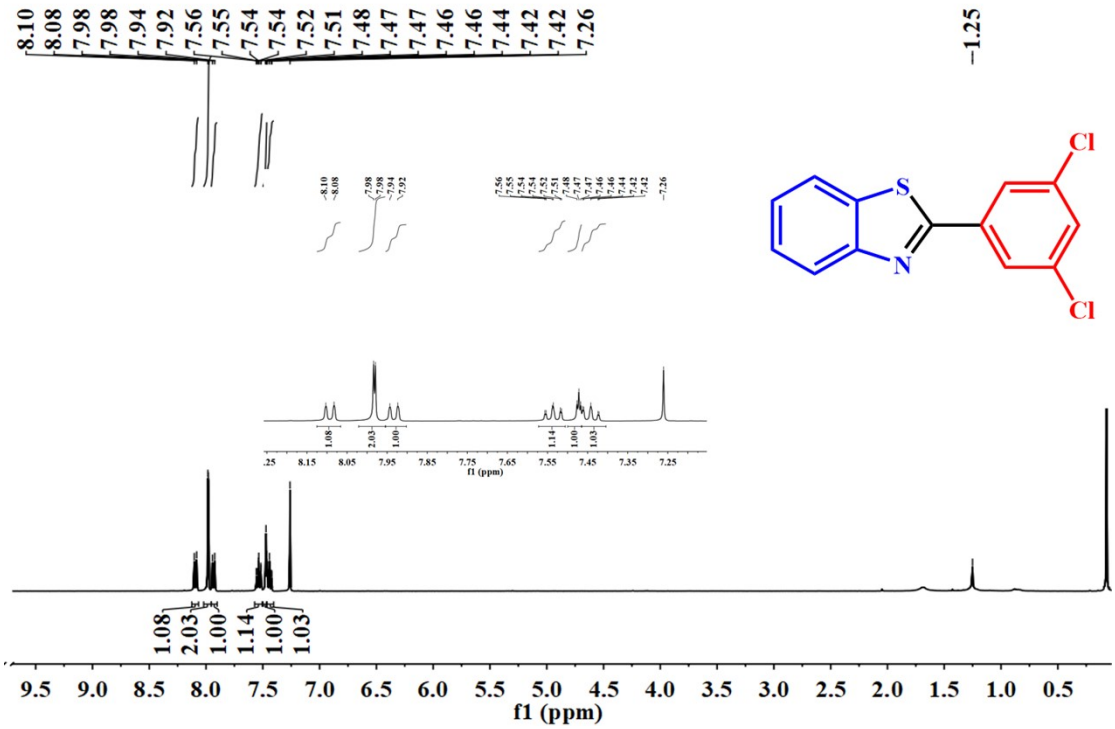
The ^{13}C-NMR spectrum of 2-(*o*-tolyl)benzo[d]thiazole (**3n**).



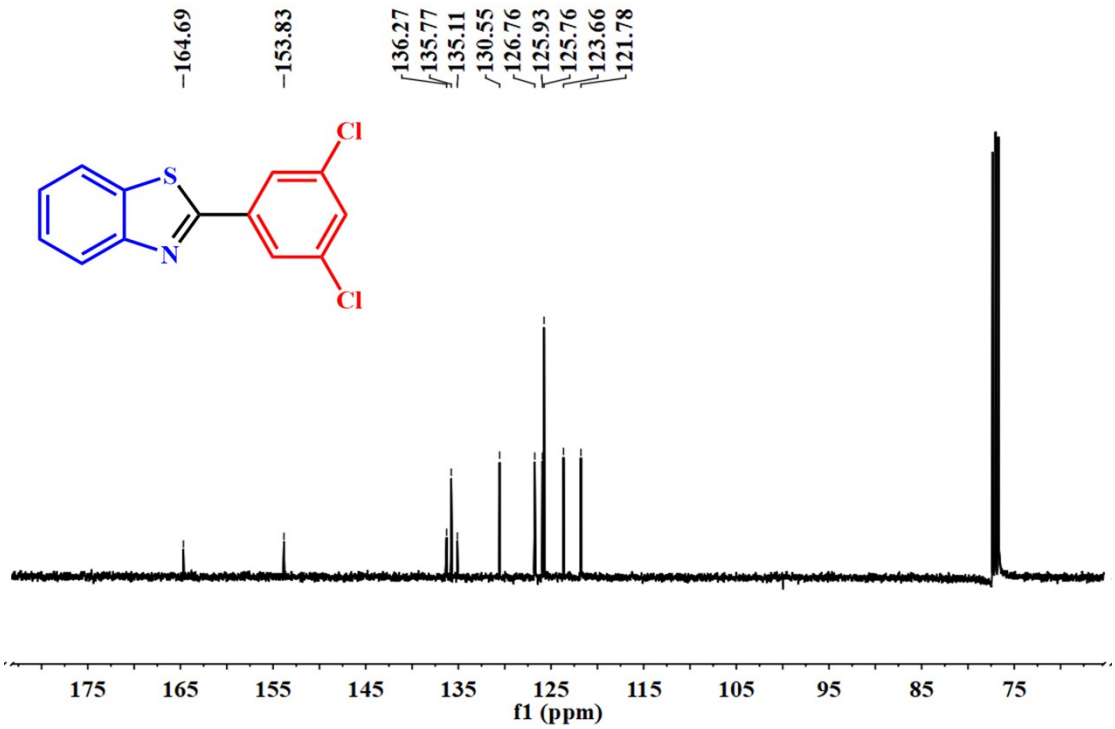
The ^{1}H-NMR spectrum of 2-(3,5-difluorophenyl)benzo[d]thiazole (**3o**).



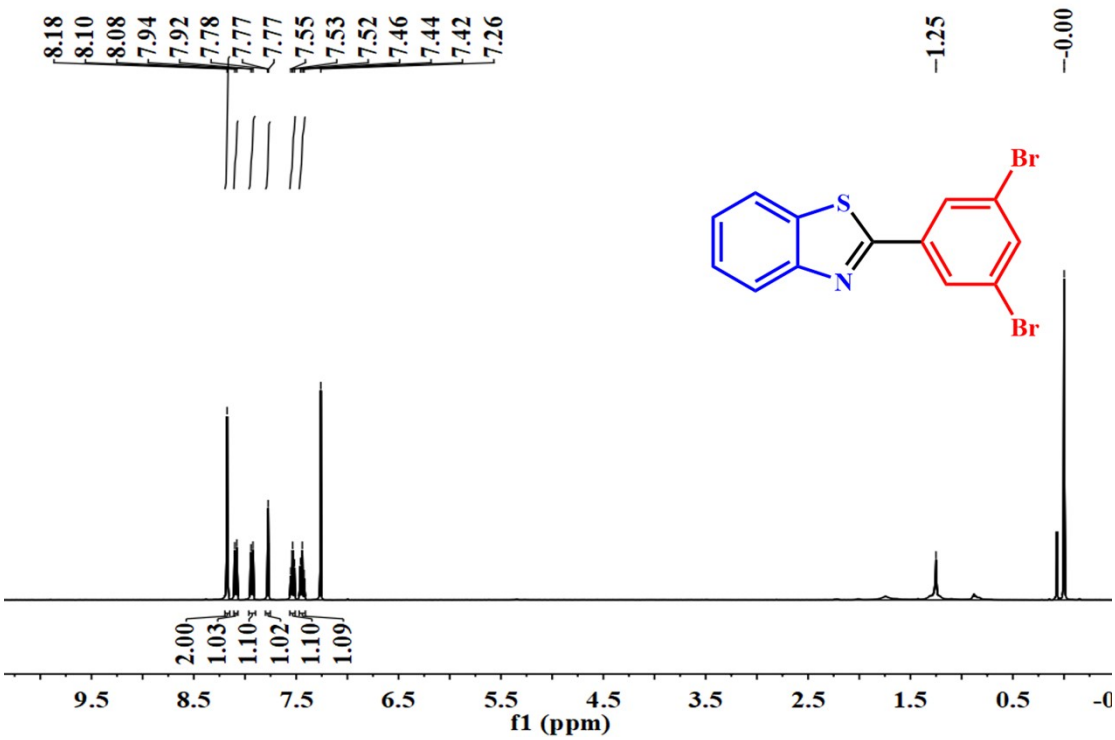
The ^{13}C-NMR spectrum of 2-(3,5-difluorophenyl)benzo[d]thiazole (**3o**).



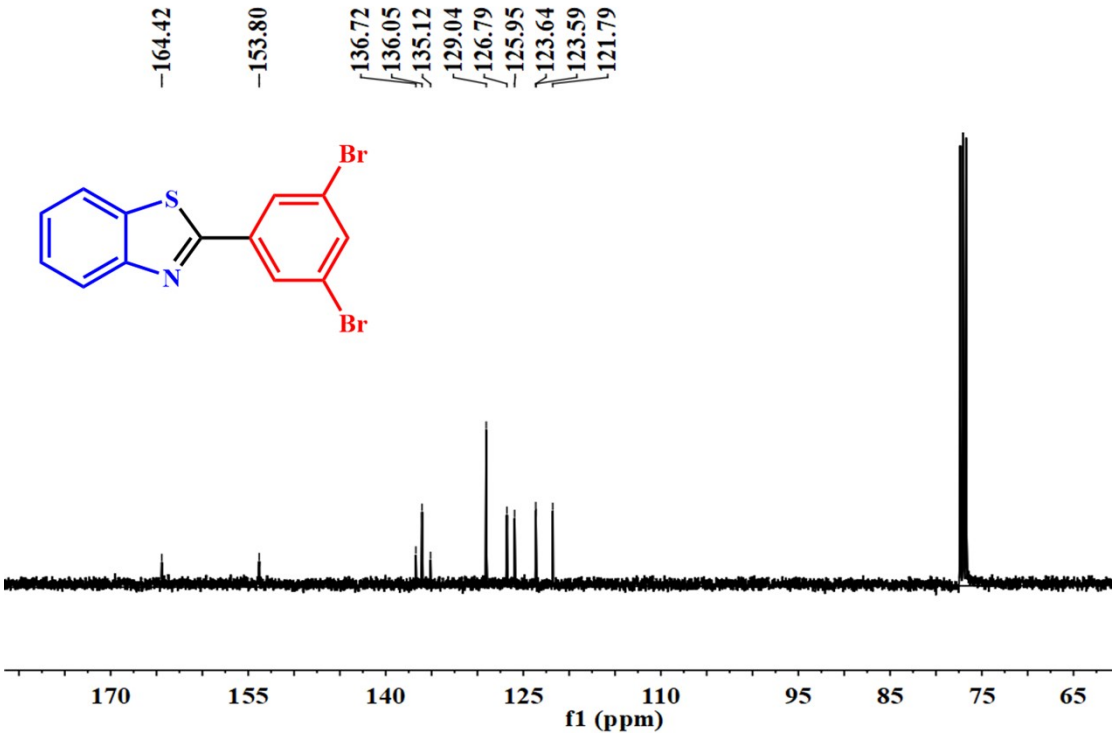
The ^{1}H-NMR spectrum of 2-(3,5-dichlorophenyl)benzo[d]thiazole (**3p**).



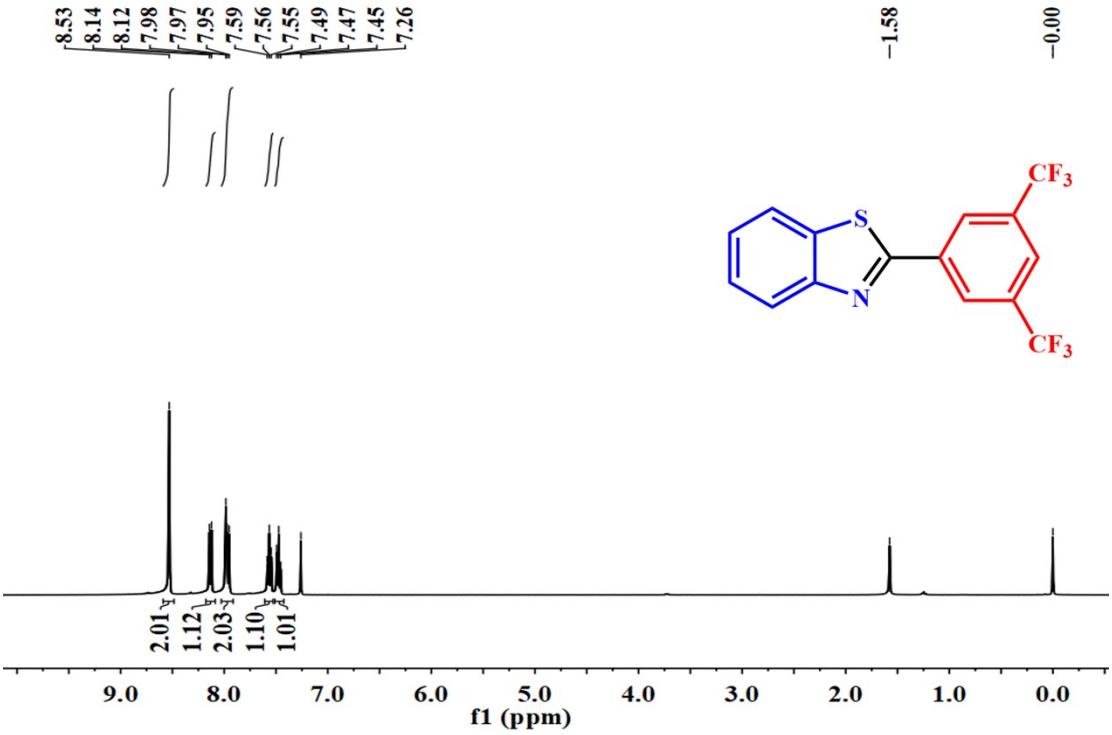
The ^{13}C-NMR spectrum of 2-(3,5-dichlorophenyl)benzo[d]thiazole (**3p**).



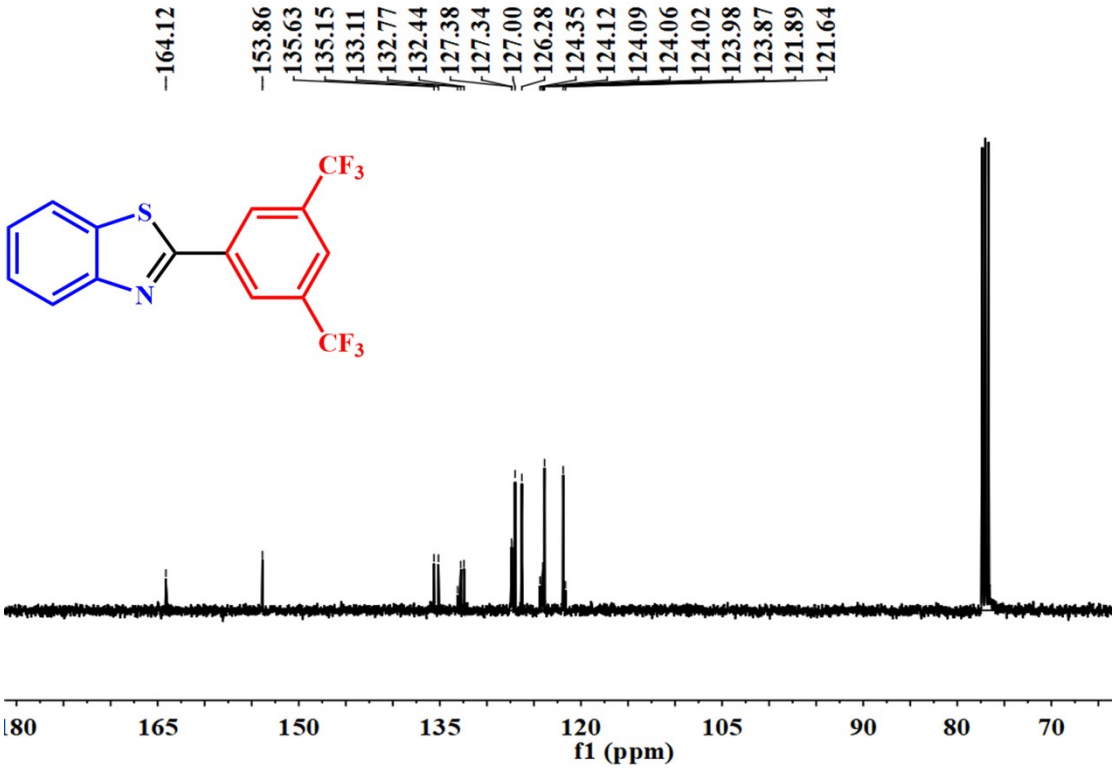
The ^{1}H-NMR spectrum of 2-(3,5-dibromophenyl)benzo[d]thiazole (**3q**).



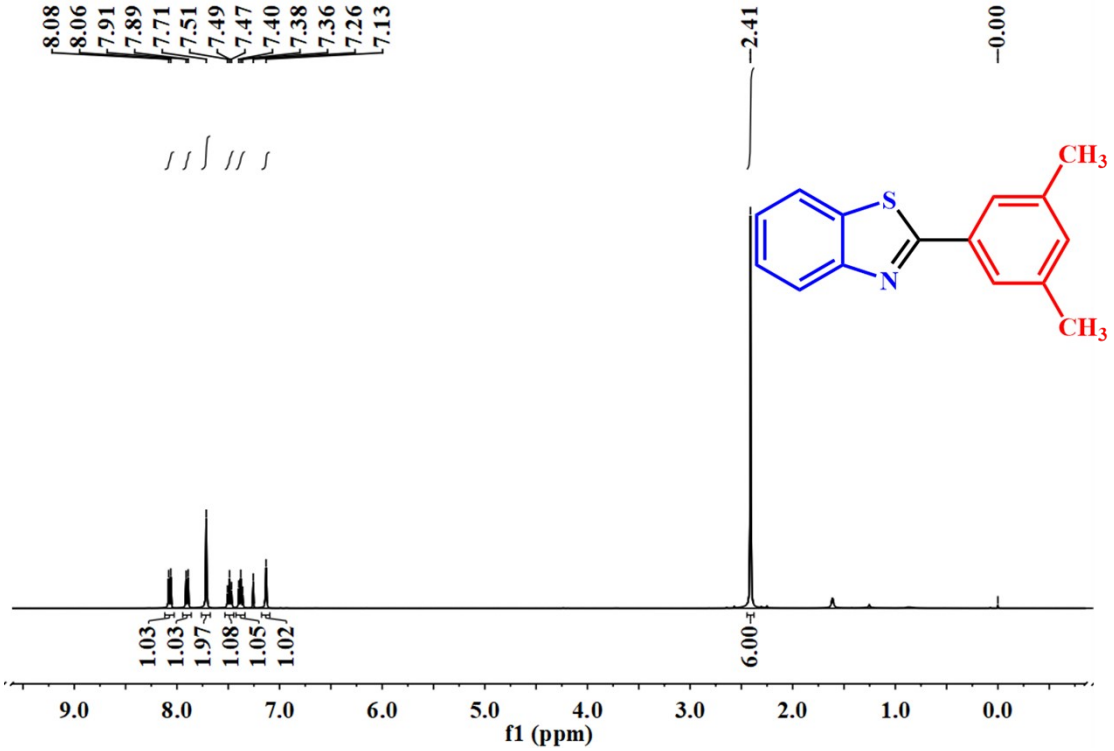
The ^{13}C-NMR spectrum of 2-(3,5-dibromophenyl)benzo[d]thiazole (**3q**).



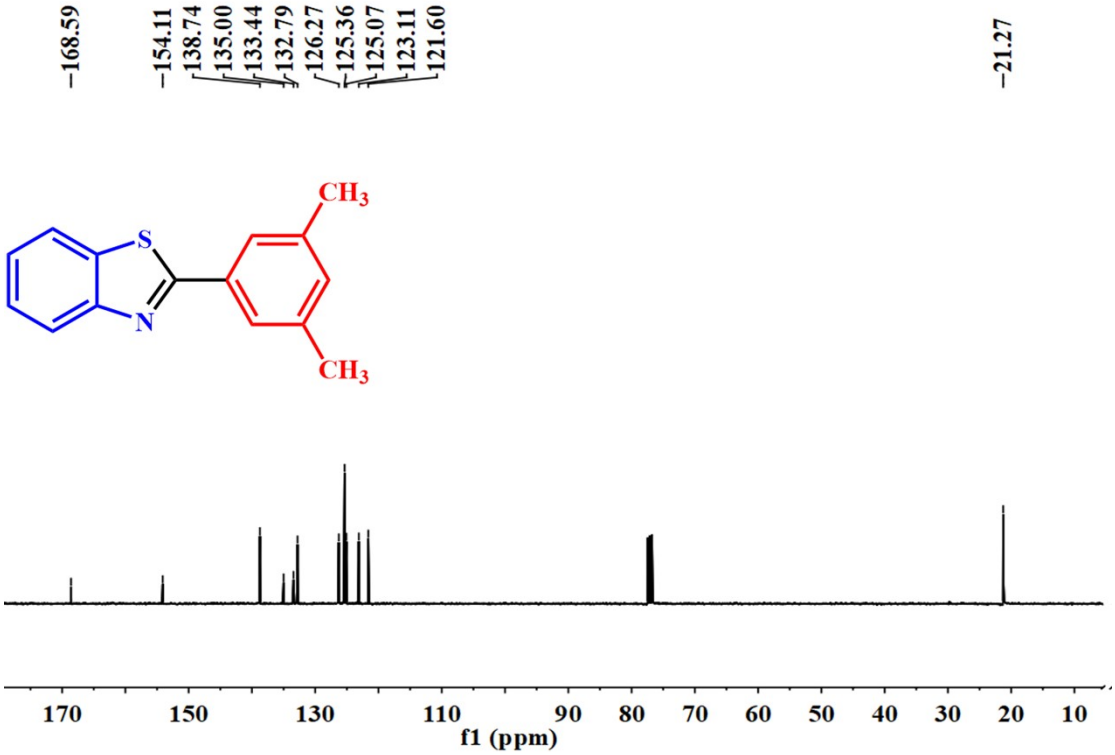
The ^{1}H-NMR spectrum of 2-(3,5-bis(trifluoromethyl)phenyl)benzo[d]thiazole (**3r**).



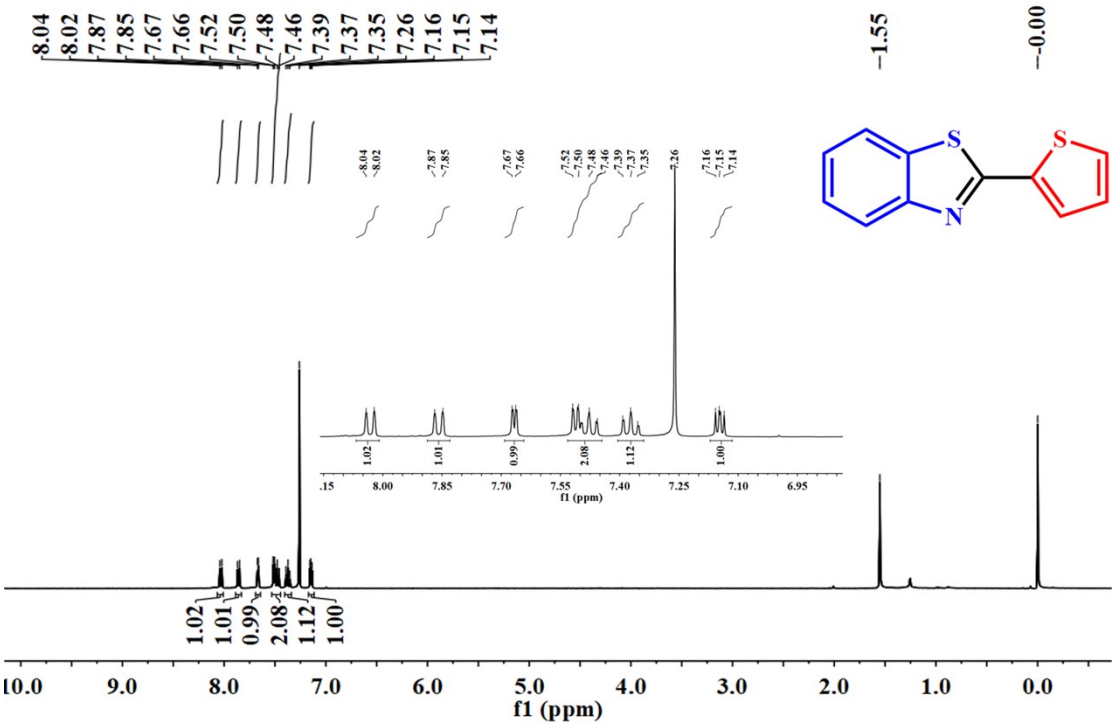
The ^{13}C-NMR spectrum of 2-(3,5-bis(trifluoromethyl)phenyl)benzo[d]thiazole (**3r**).



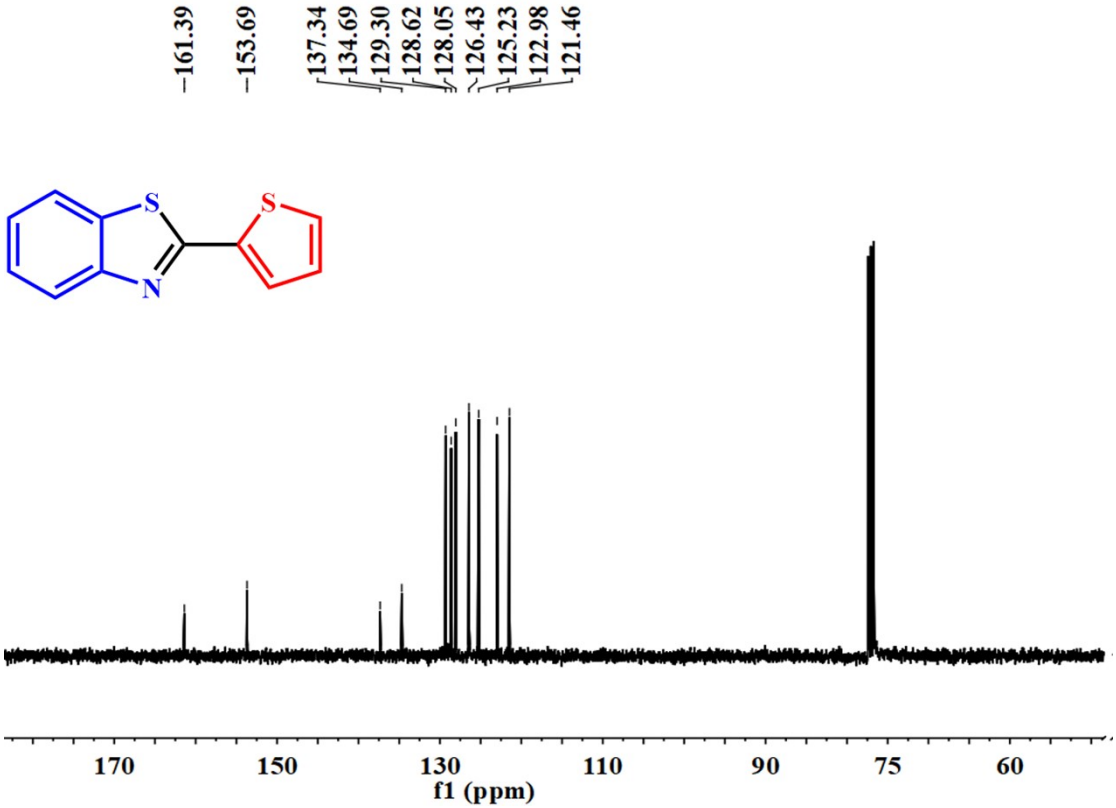
The ^{1}H-NMR spectrum of 2-(3,5-dimethylphenyl)benzo[d]thiazole (**3s**).



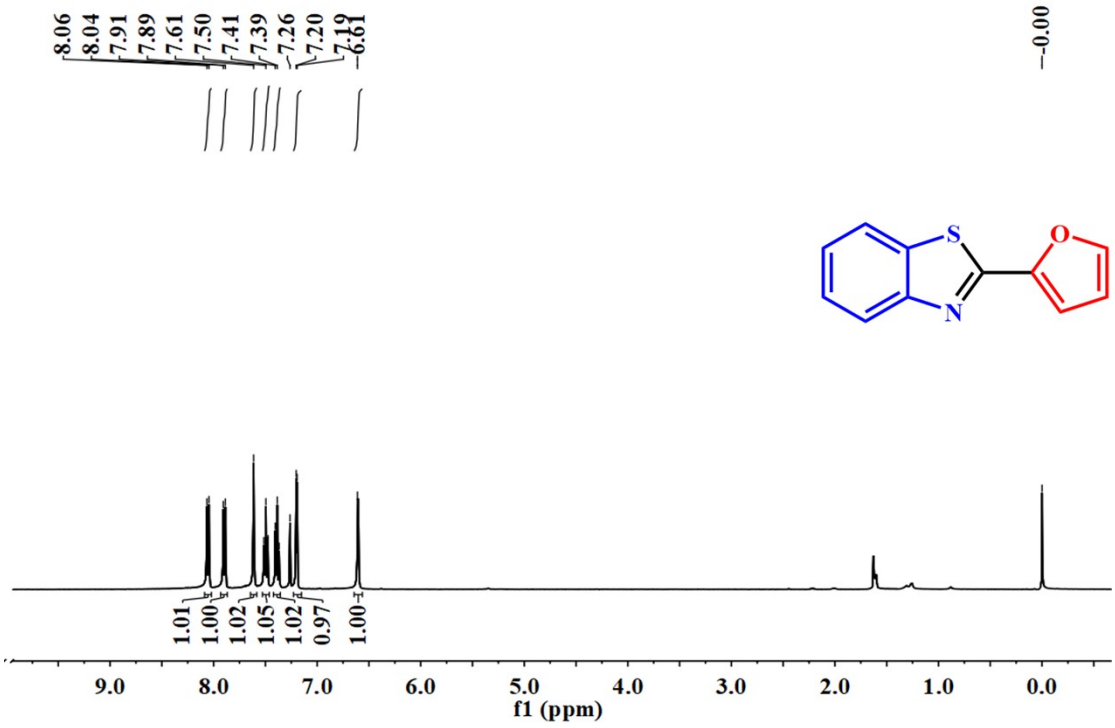
The ^{13}C-NMR spectrum of 2-(3,5-dimethylphenyl)benzo[d]thiazole (**3s**).



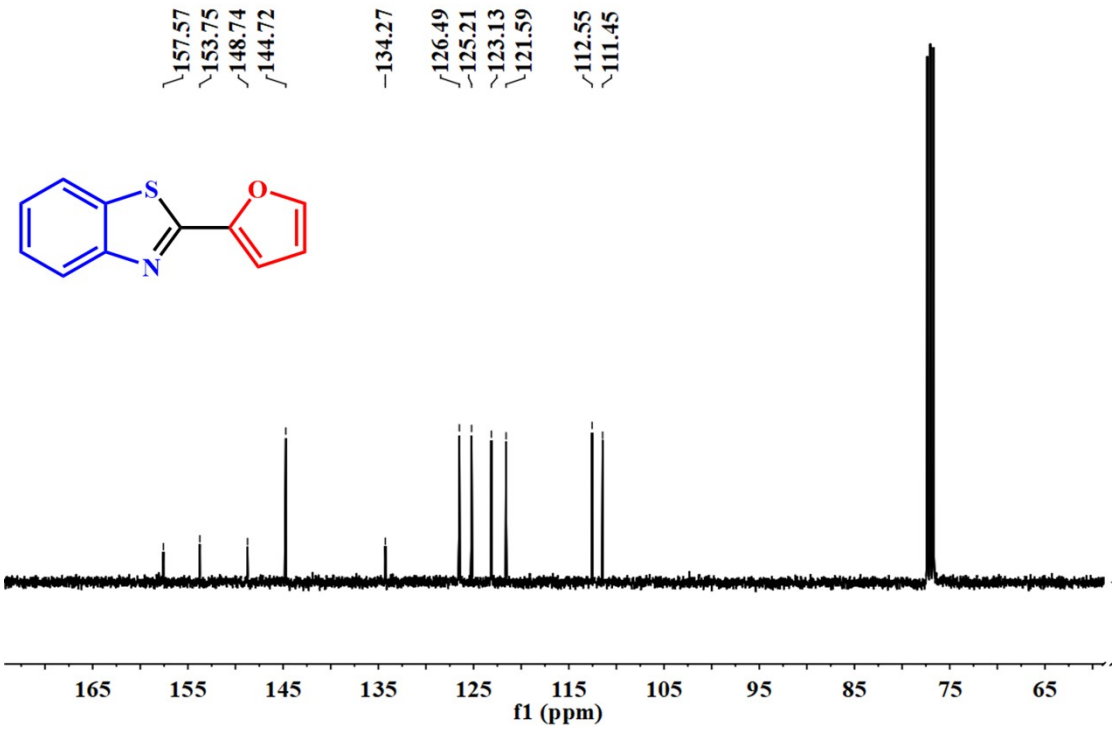
The ^{1}H-NMR spectrum of 2-(thiophen-2-yl)benzo[d]thiazole (**3t**).



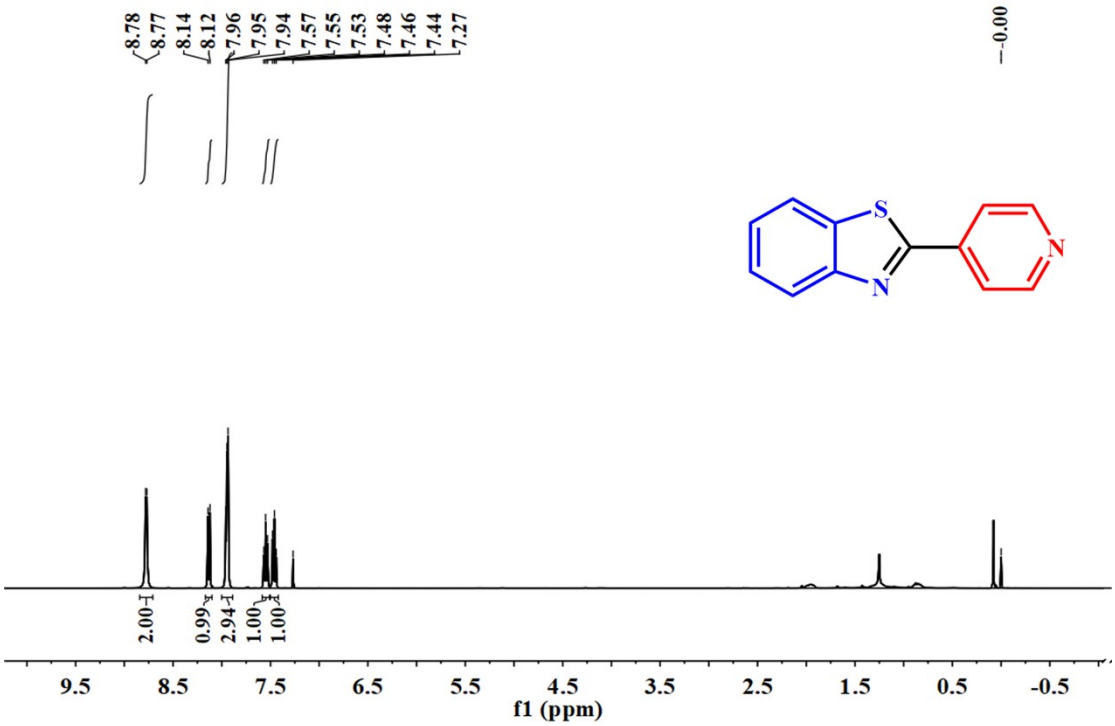
The ^{13}C-NMR spectrum of 2-(thiophen-2-yl)benzo[d]thiazole (**3t**).



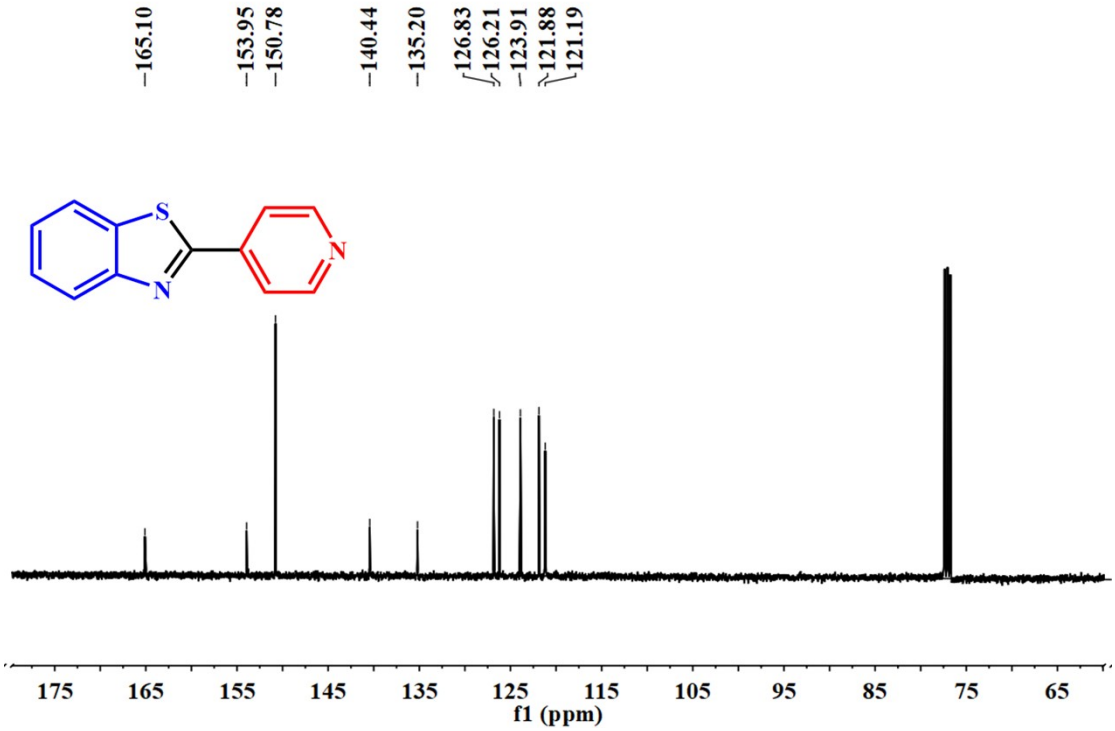
The ^{1}H-NMR spectrum of 2-(furan-2-yl)benzo[d]thiazole (**3u**).



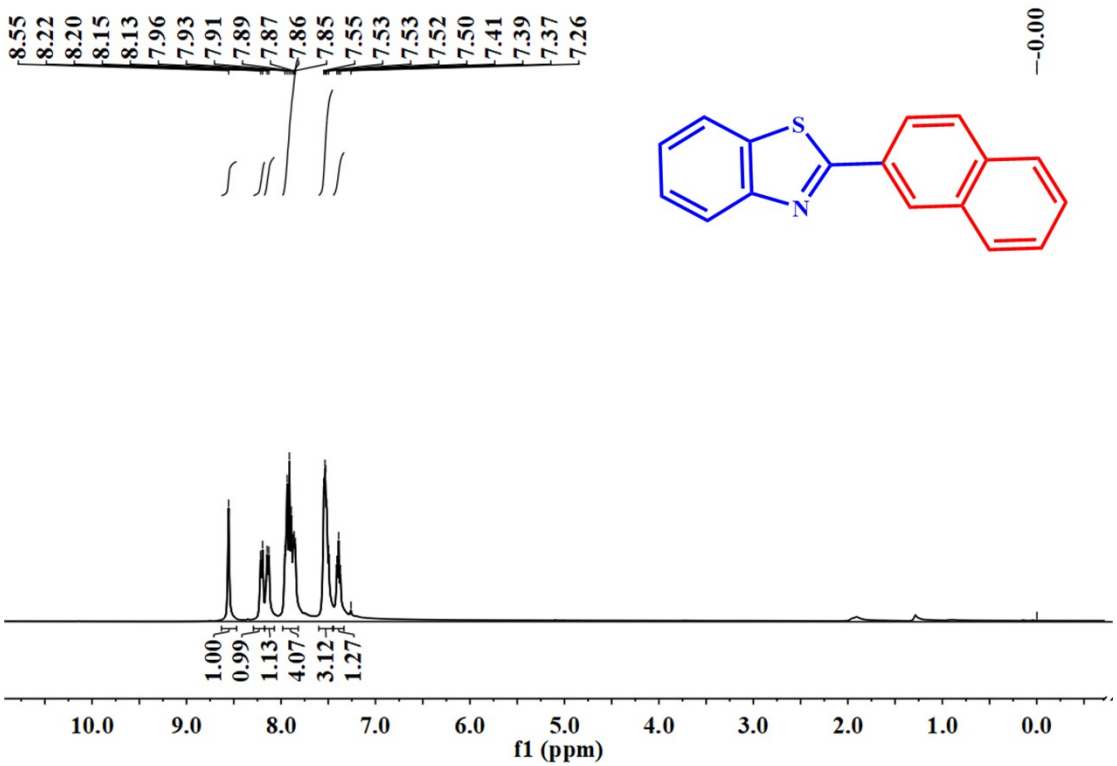
The ^{13}C-NMR spectrum of 2-(furan-2-yl)benzo[d]thiazole (**3u**).



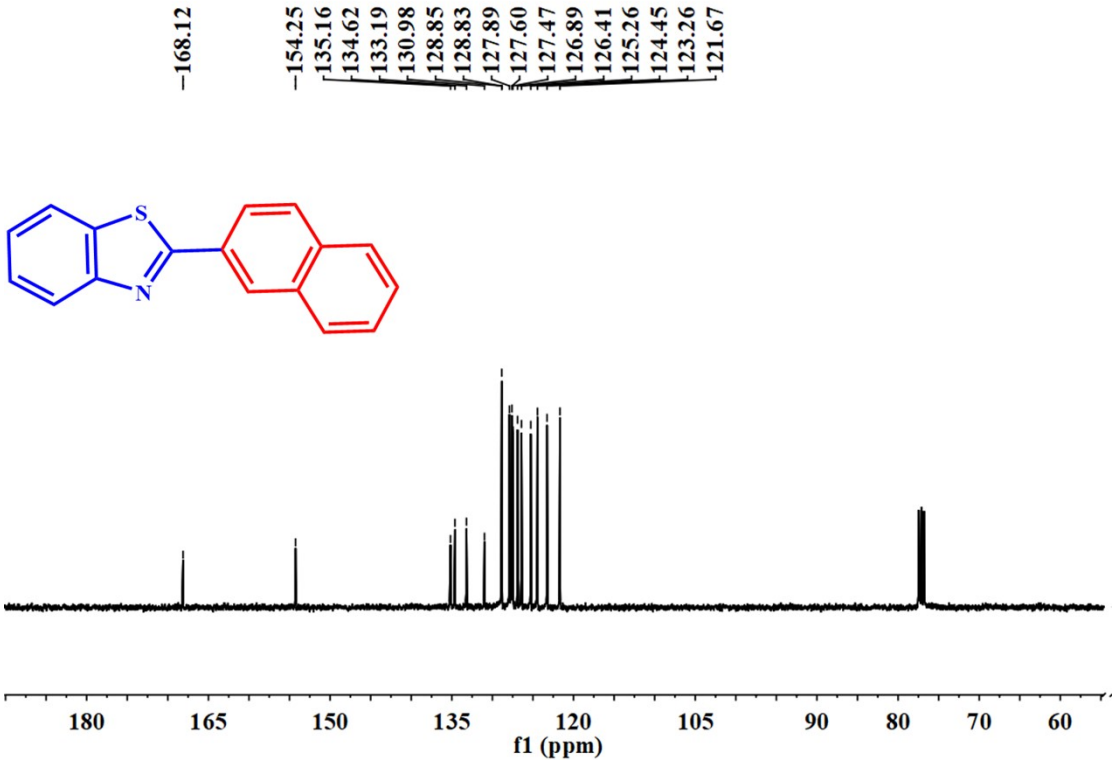
The ^{1}H-NMR spectrum of 2-(pyridin-4-yl)benzo[d]thiazole (**3v**).



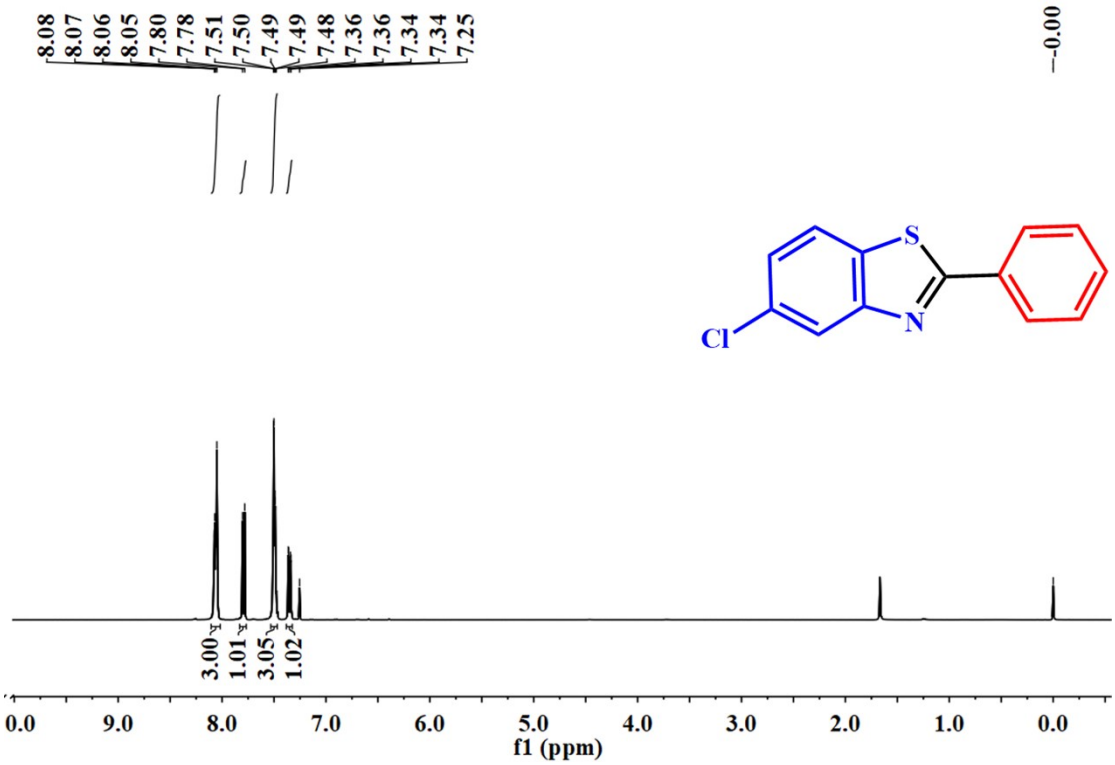
The ^{1}H-NMR spectrum of 2-(pyridin-4-yl)benzo[d]thiazole (**3v**).



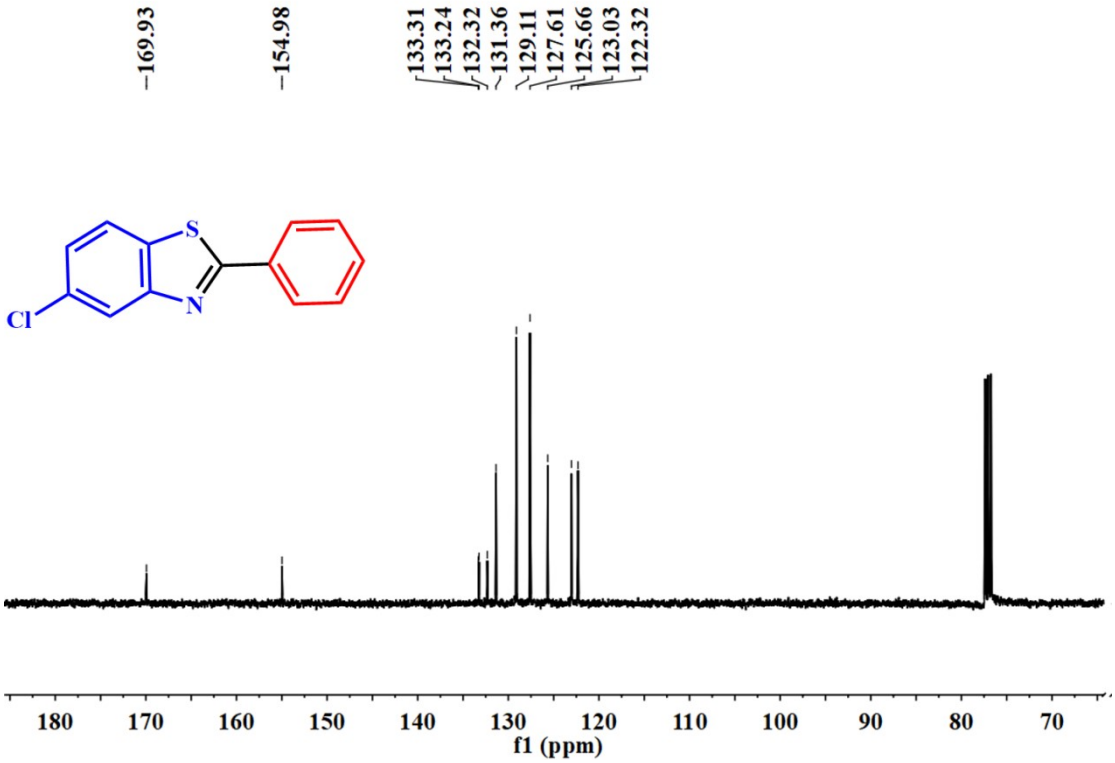
The ^{1}H-NMR spectrum of 2-(naphthalen-2-yl)benzo[d]thiazole (**3w**).



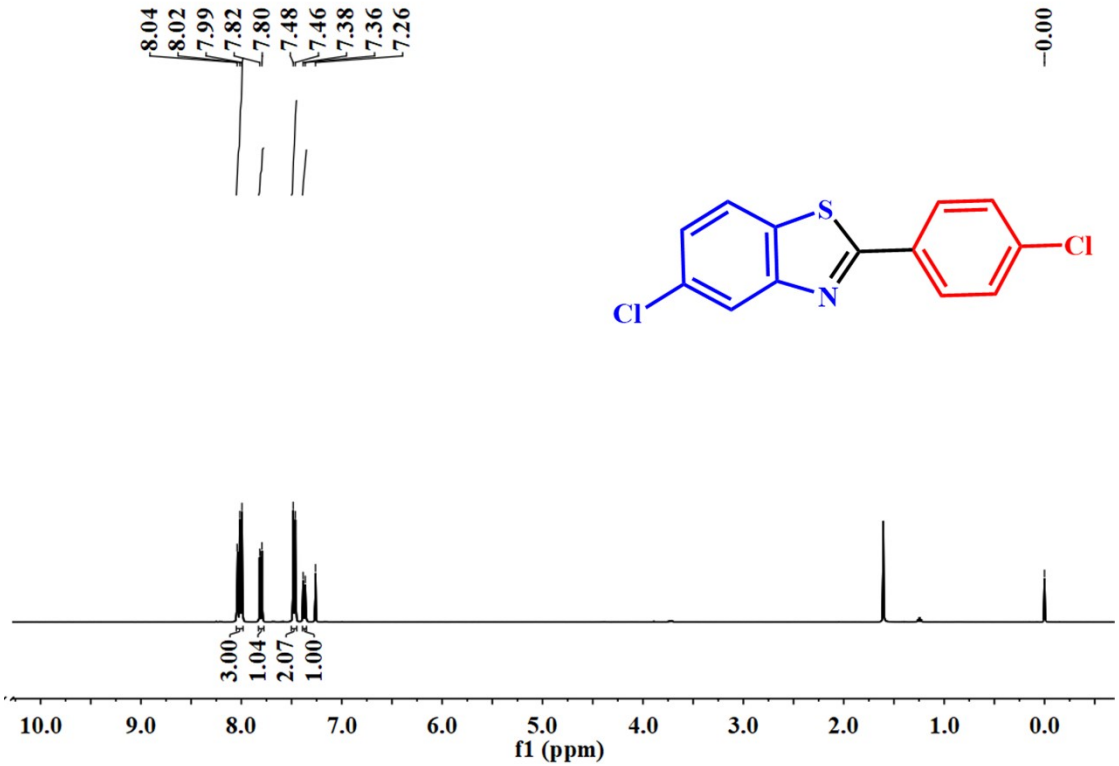
The ^{13}C-NMR spectrum of 2-(naphthalen-2-yl)benzo[d]thiazole (**3w**).



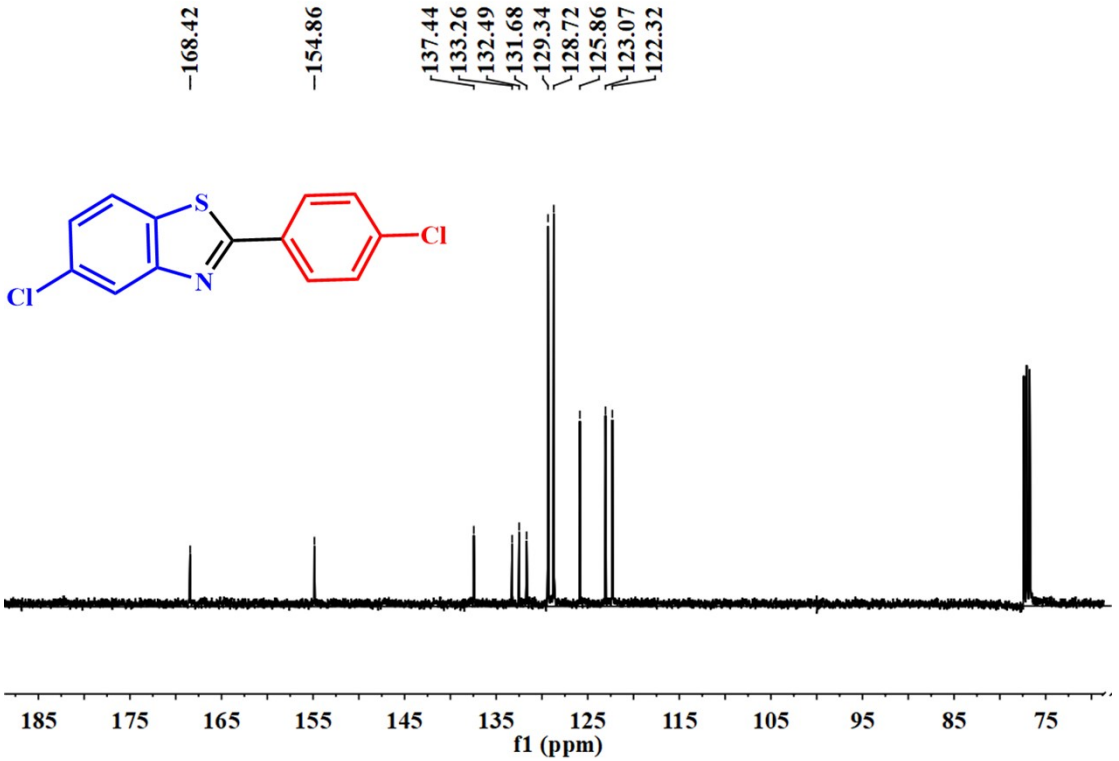
The ^{1}H-NMR spectrum of 5-chloro-2-phenylbenzo[d]thiazole (**4a**).



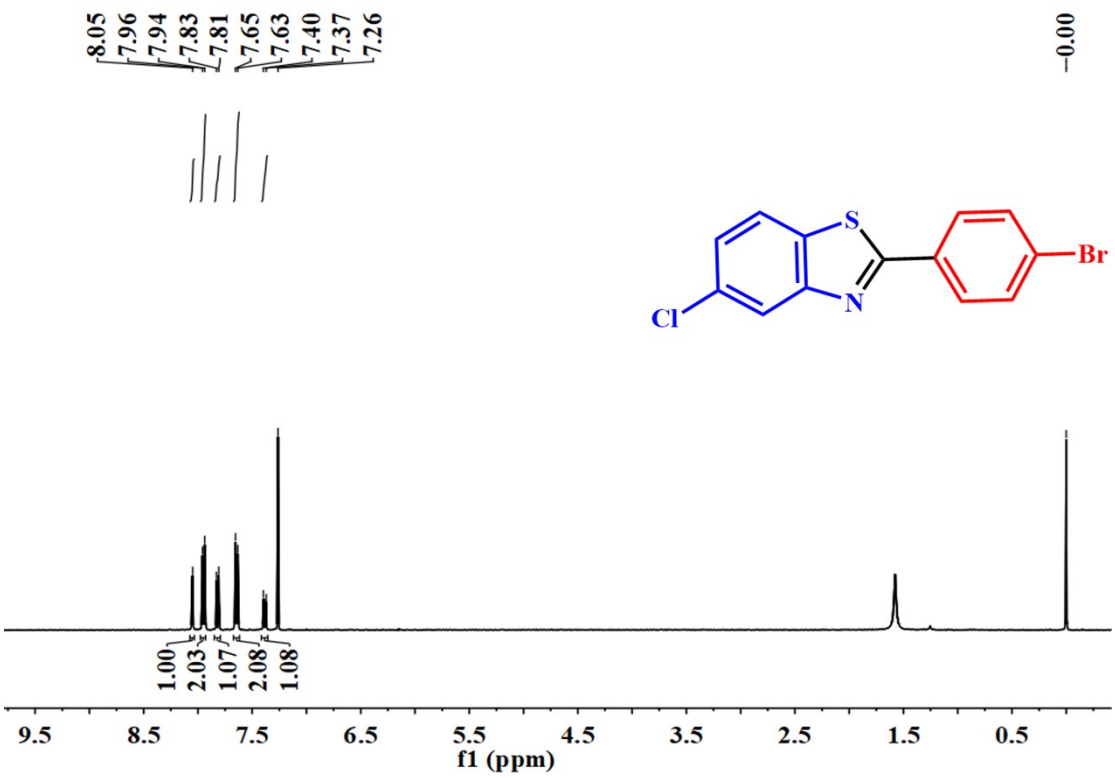
The ^{13}C-NMR spectrum of 5-chloro-2-phenylbenzo[d]thiazole (**4a**).



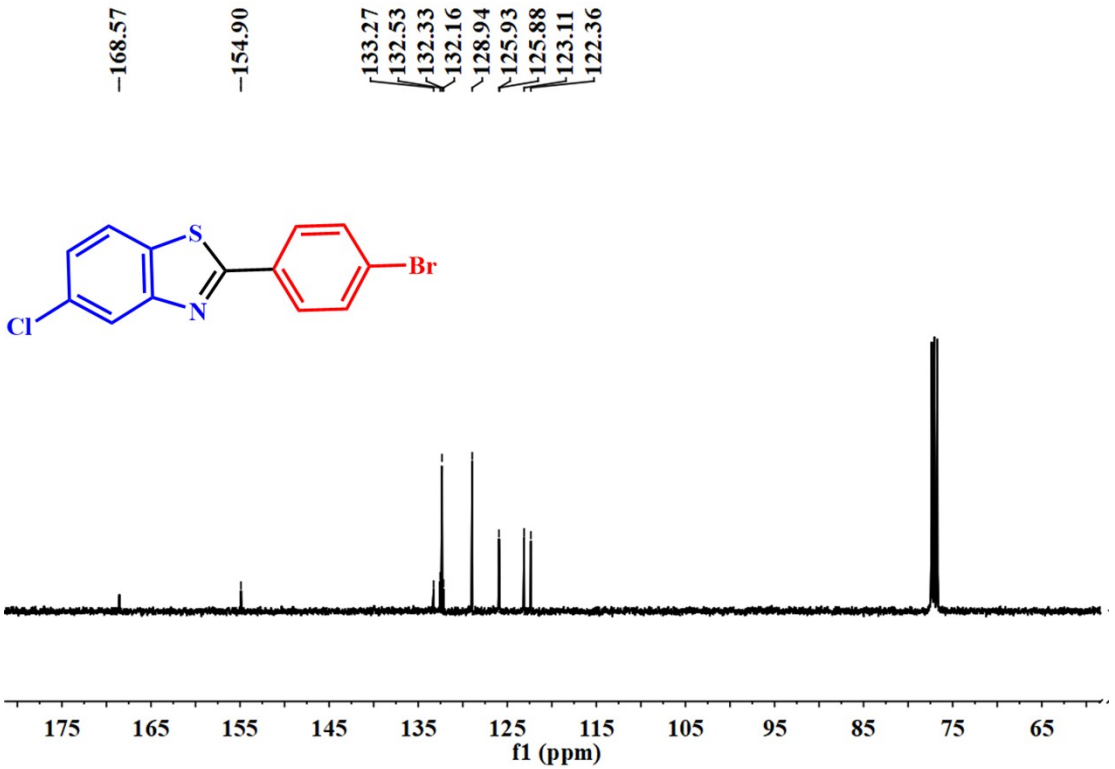
The ^{1}H-NMR spectrum of 5-chloro-2-(4-chlorophenyl)benzo[d]thiazole (**4b**).



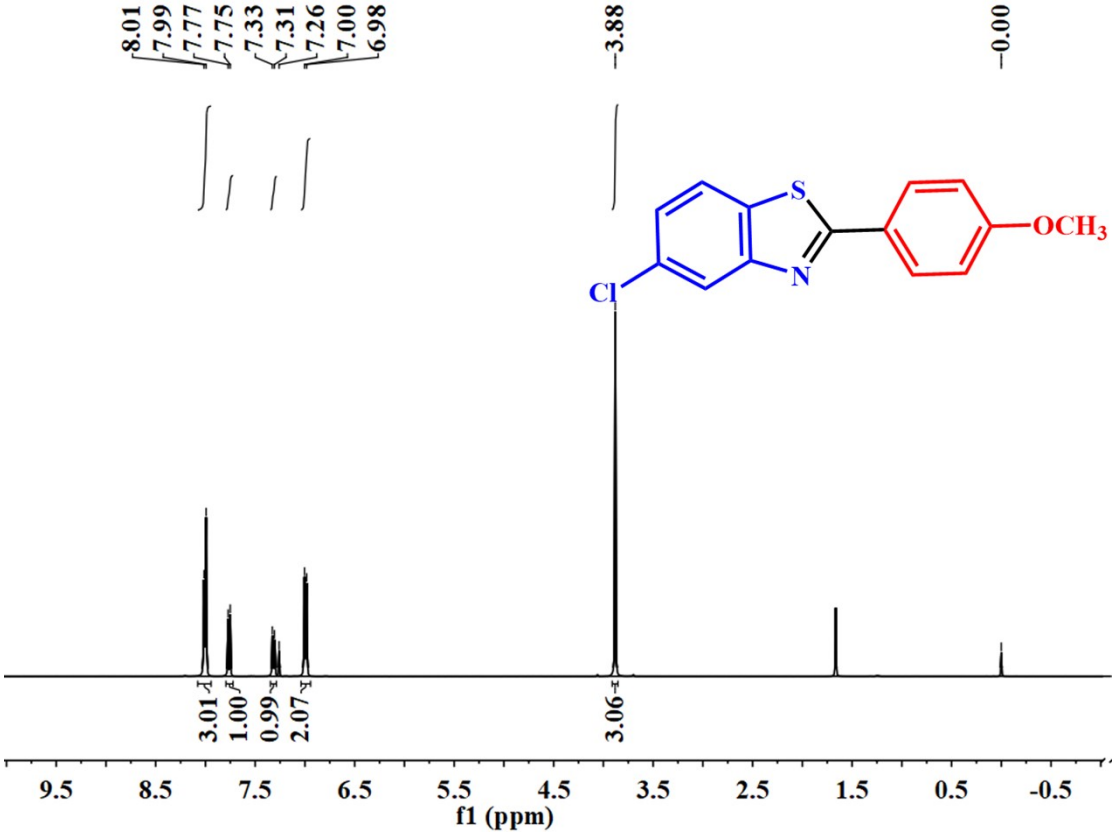
The ^{13}C-NMR spectrum of 5-chloro-2-(4-chlorophenyl)benzo[d]thiazole (**4b**).



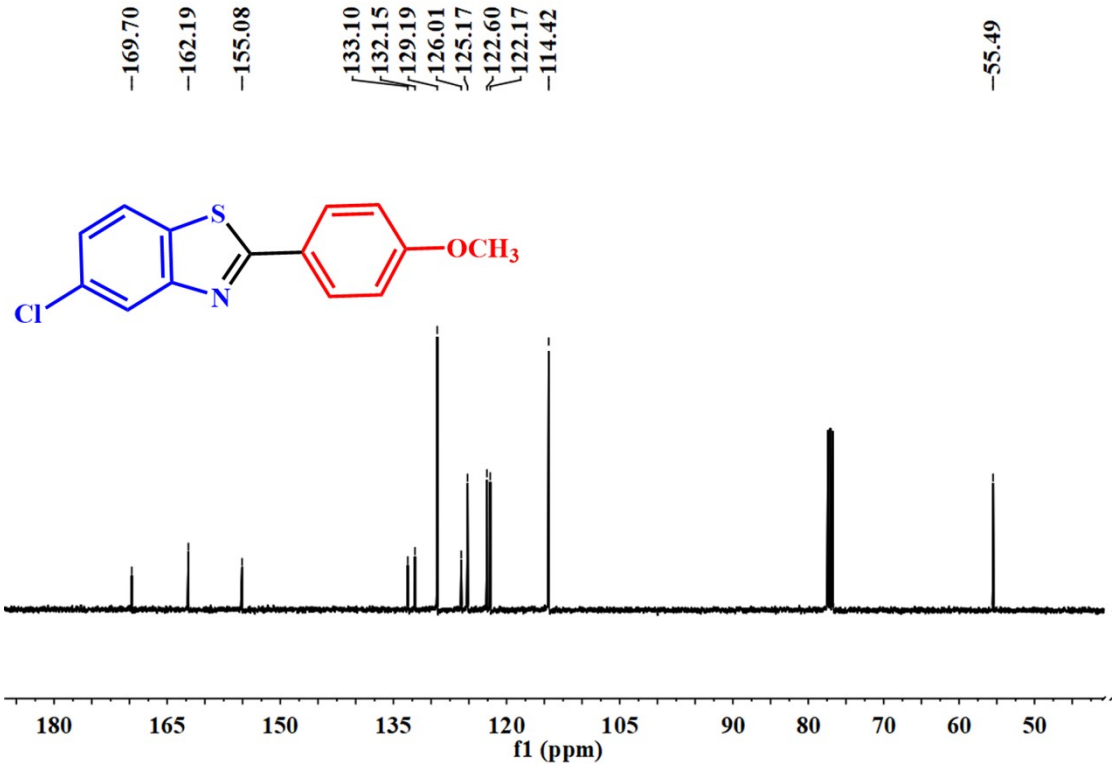
The ^{1}H-NMR spectrum of 2-(4-bromophenyl)-5-chlorobenzo[d]thiazole (**4c**).



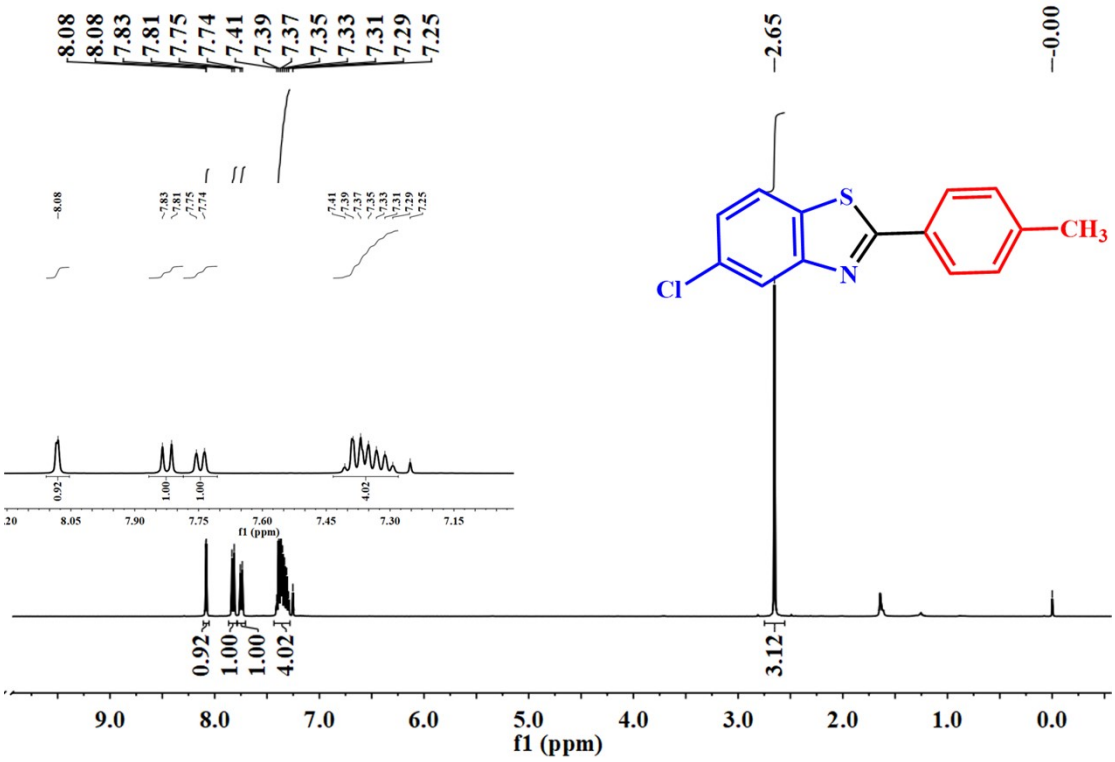
The ^{13}C-NMR spectrum of 2-(4-bromophenyl)-5-chlorobenzo[d]thiazole (**4c**).



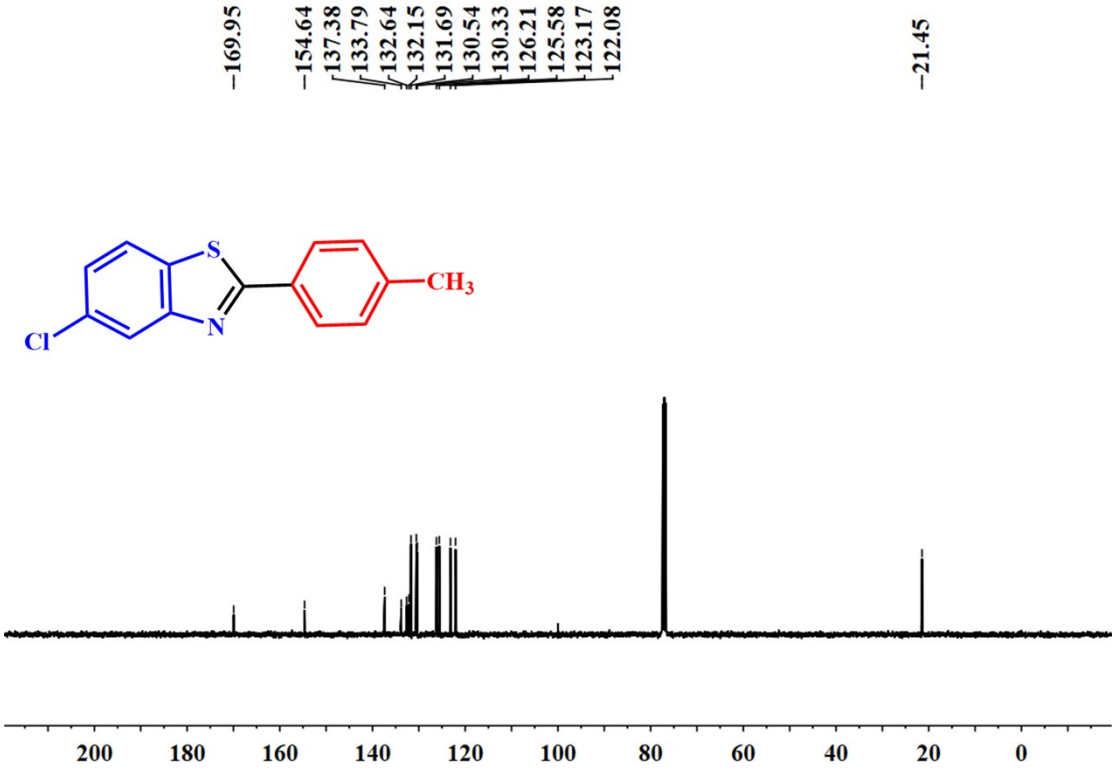
The ^{1}H-NMR spectrum of 5-chloro-2-(4-methoxyphenyl)benzo[d]thiazole (**4d**).



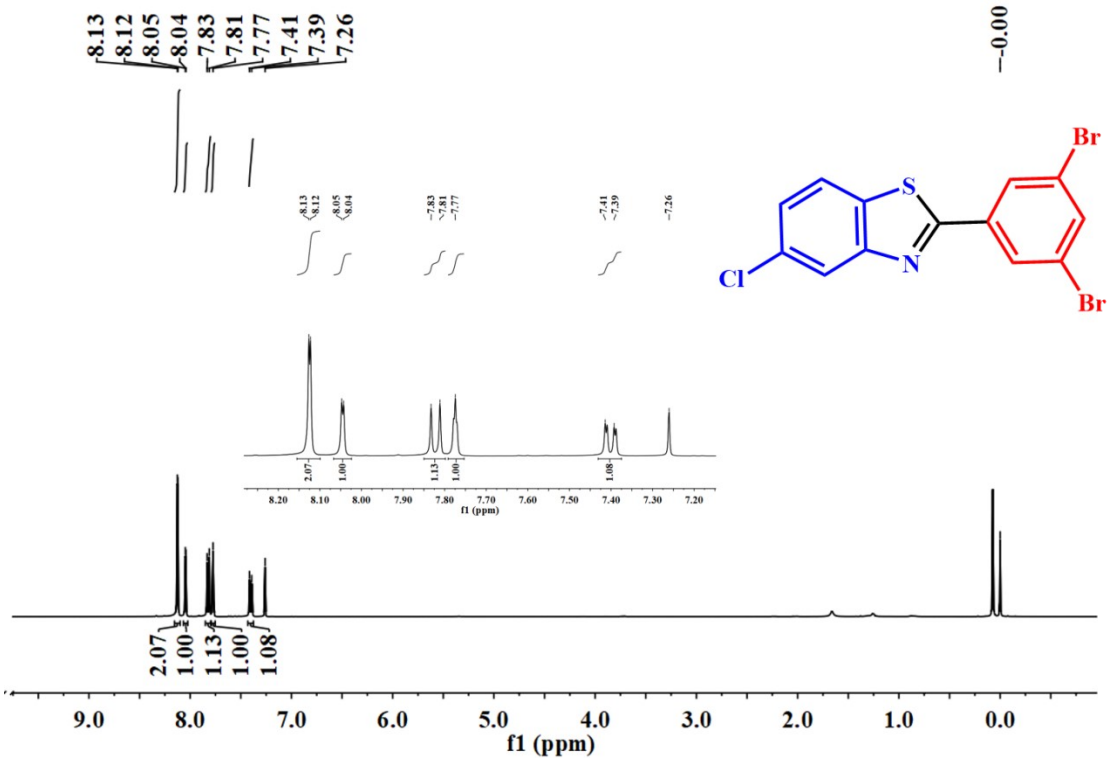
The ^{13}C-NMR spectrum of 5-chloro-2-(4-methoxyphenyl)benzo[d]thiazole (**4d**).



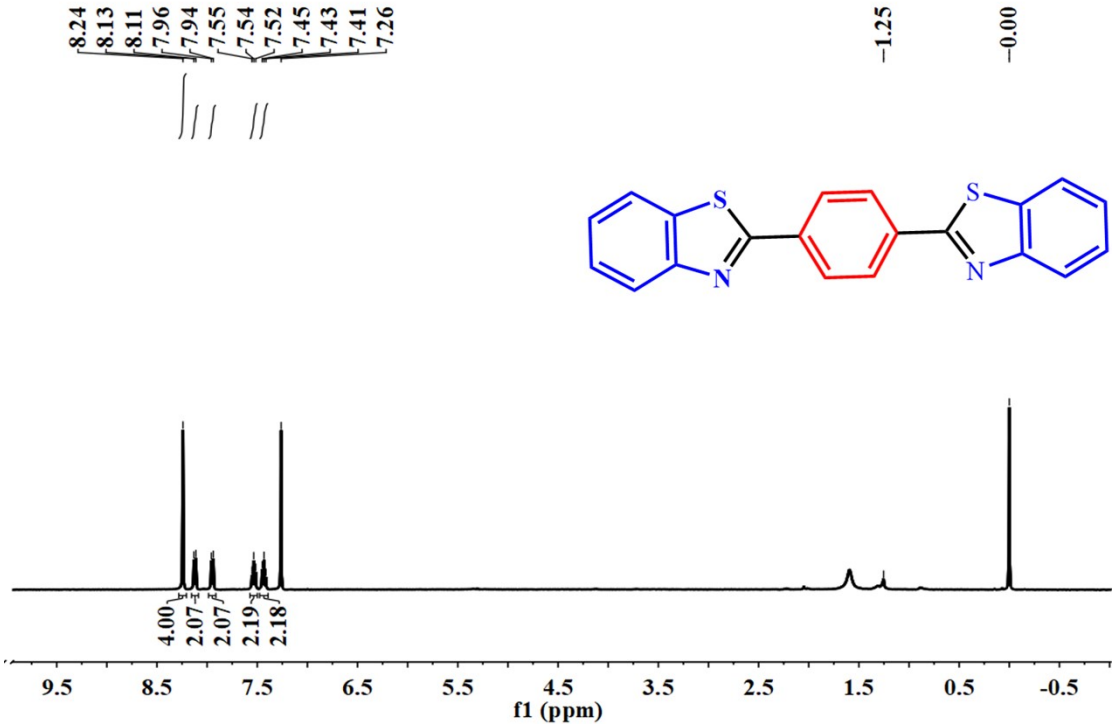
The ^{1}H-NMR spectrum of 5-chloro-2-(*p*-tolyl)benzo[d]thiazole (**4e**).



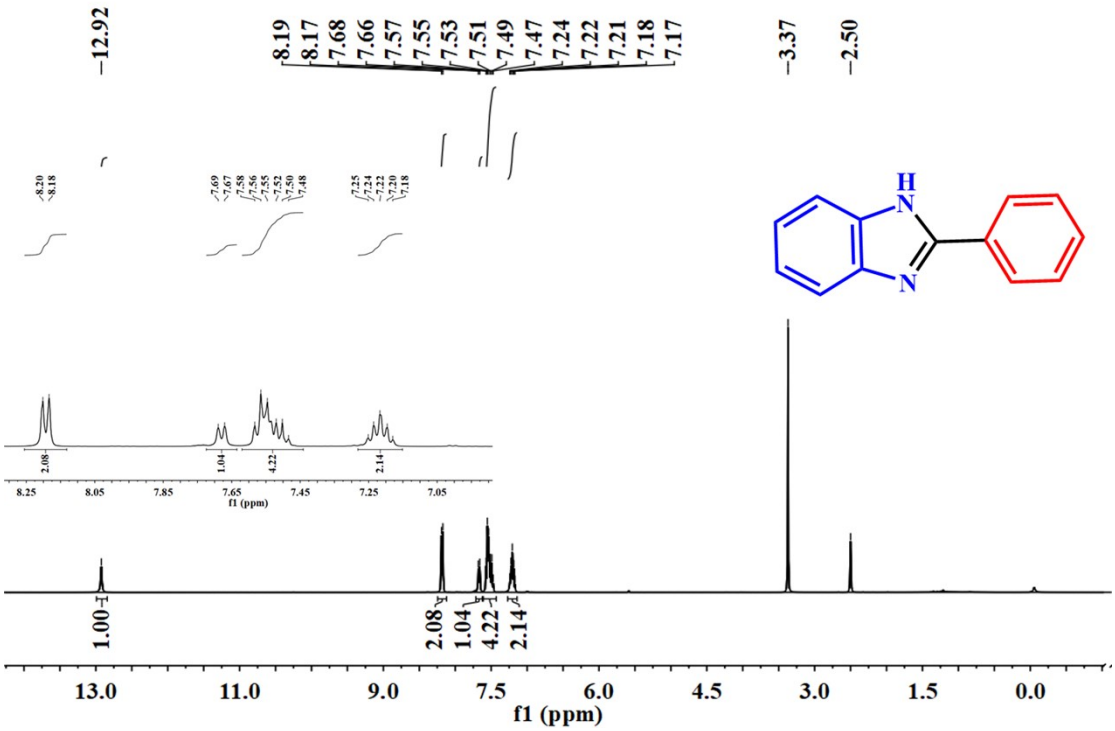
The ^{13}C-NMR spectrum of 5-chloro-2-(*p*-tolyl)benzo[d]thiazole (**4e**).



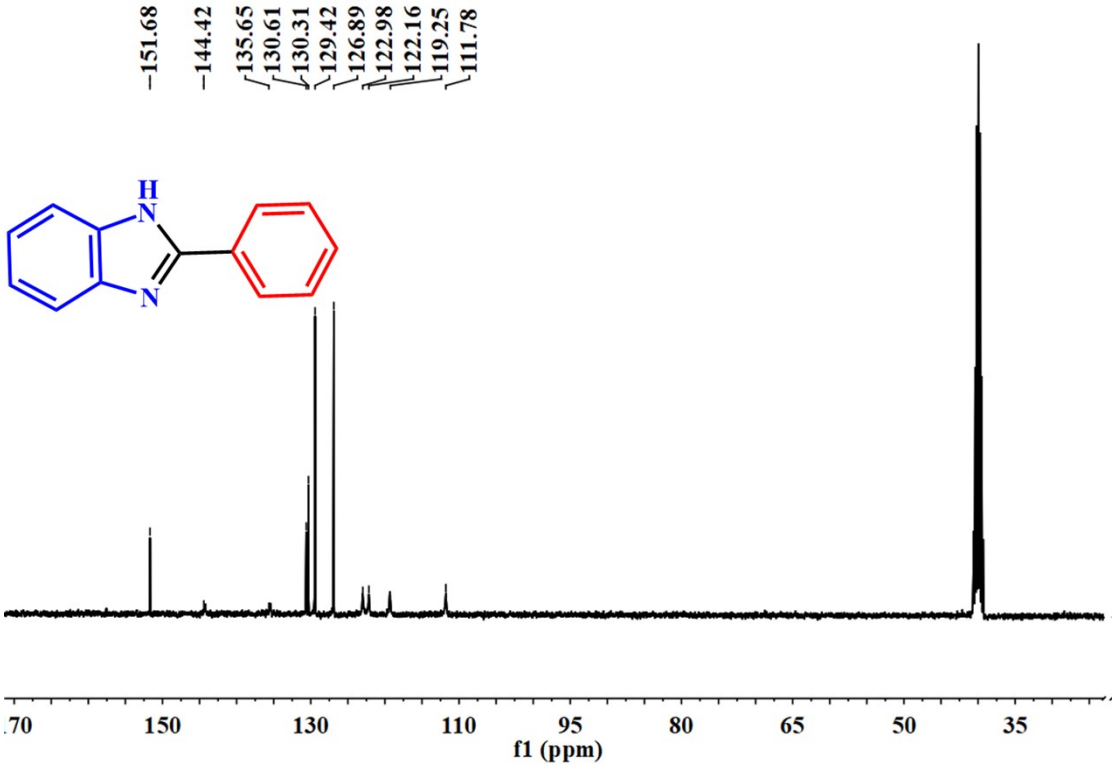
The ^{1}H-NMR spectrum of 5-chloro-2-(3,5-dibromophenyl)benzo[d]thiazole (**4f**).



The ^{1}H-NMR spectrum of 1,4-bis(benzo[d]thiazol-2-yl)benzene (**4g**).



The ^{1}H-NMR spectrum of 2-phenyl-1H-benzo[d]imidazole.



The ^{13}C-NMR spectrum of 2-phenyl-1H-benzo[d]imidazole.

Section S8. Notes and references

1 S.M. Petryk, J. Szymkowiak, B. Gierczyk, G. Spolnik, L. Popenda, A. Janiak and M. Kwit, *Chiral, Org. Biomol. Chem.,* 2016, **14**, 7495−7499.

2 S. Haldar, D. Chakraborty, B. Roy, G. Banappanavar, K. Rinku, D. Mullangi, P. Hazra, D. Kabra and R. Vaidhyanathan, *J. Am. Chem. Soc.,* 2018, **140** 13367−13374.

3 S. Liu, Z. Liu, Q. Su and Q. Wu, *Micropor. Mesopor. Mat.,* 2022, **333** 111737−111743.

4 J. Feng, C. Hu, Y. Bai, Q. Su, S. Liu, M. Li, W. Wang and Q. Wu, *Micropor. Mesopor. Mat.,* 2024, **366** 112971.

5 S. Li, J. Yin, H. Zhang and K.A.I. Zhang, ACS Appl. Mater. Interfaces., 2023,**15**, 2825−2831.

6 W. Sun, H. Chen, K. Wang, X. Wang, M. Lei, C. Liu, Q. Zhong, *Mol. Catal.,* 2021, **510**, 111693.

7 Y. Zhu, S. Li, X. Yang, S. Wang, Y. Zhang, *J. Mater. Chem. A,* 2011, **10** 13978−13986.

8 S. Dasa, S. Samantaa, S. K. Majia, P. K. Samantaa, A. K. Duttaa, D. N. Srivastavab, B. Adhikarya, P. Biswas, *Tetrahedron. Lett.*,2013, **54**, 1090-1096.

9 Z. Liu, Z. Chen, H. Tong, M. Ji and W. Chu, *Green Chem*., 2023, **25**, 5182-5205.

10 X. Chen, Q. Zhong, X. Ma, S. Li, W. Sun, C. Liu, *J. Catal.,* 2024, **429**, 115274.

11 Y. Xu, N. Zhao, F. Li, H. Xie, J. Wu, C. Wang, Z. Li, L. Wang, *Mol. Catal.,* 2022, **533**,112784.