

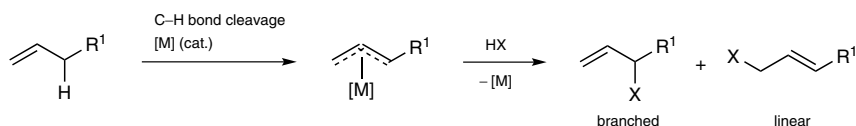
## Abstracts

p 1

### 2.1 C–C and C–X Bond Formation by Allylic C–H Activation

*G. Liu and P. Chen*

This chapter documents recent studies into allylic functionalization via C–H activation processes catalyzed by metals such as palladium, rhodium, ruthenium, copper, and iron. The focus is on the formation of C–C, C–N, and C–O bonds reported in the last two decades, but more recent developments involving the formation of other C–X bonds, such as C–F and C–Si are also highlighted.



[M] = Pd, Rh, Ru, Cu, Fe, etc.; X = C, N, O, Si, F, etc.

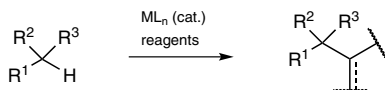
**Keywords:** allylic C–H activation · alkenes · palladium · rhodium · ruthenium · copper · iron · allylic amines · allylic acetates

p 37

### 2.2 C–C Bond Formation by Alkyl C–H Activation

*O. Baudoin*

In comparison to the wealth of methods recently developed for the catalytic functionalization of the C(sp<sup>2</sup>)–H bonds of arenes and hetarenes, relatively little work has focused on the functionalization of the unactivated C(sp<sup>3</sup>)–H bonds of alkyl fragments. This chapter highlights selected examples of the fast-growing literature on the catalytic functionalization of unactivated C(sp<sup>3</sup>)–H bonds through organometallic C–H activation, with an emphasis on the most synthetically useful methods. It covers heteroatom-directed C(sp<sup>3</sup>)–H activation with regard to cross coupling with alkenes, alkynes, and carbon monoxide, organoboron reagents, diaryliodonium salts, and organic halides. Also included is C(sp<sup>3</sup>)–H activation/intramolecular C–C coupling induced by oxidative addition and non-directed intermolecular C(sp<sup>3</sup>)–H arylation.



**Keywords:** C(sp<sup>3</sup>)–H bond activation · carbon–carbon coupling · transition metals · palladium catalysis · ruthenium catalysis · alkylation

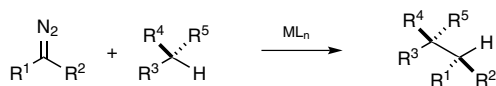
p 63

### 2.3 C–C Bond Formation Using Carbenes

*X. Cui and X. P. Zhang*

Transition-metal-catalyzed carbene C–H insertion has been developed as one of the most direct and effective methods for the construction of C–C bonds from C–H bonds. During the past two decades, a number of transition-metal-based catalytic systems have been established for asymmetric C–H functionalization via carbene insertion. Synthetically use-

ful systems have been developed to functionalize C–H bonds in both intermolecular and intramolecular fashions. In this chapter, highly selective and practical catalytic systems for stereoselective C–H functionalization via catalytic carbene transfer are summarized. Literature reports are classified and discussed according to the type of C–H bond. This review focuses mainly on the issue of stereoselectivity, particularly on enantioselectivity.



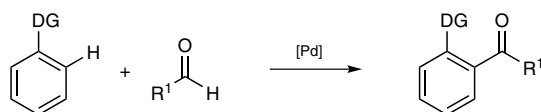
**Keywords:** asymmetric synthesis • C–H functionalization • transition-metal catalysis • diazo reagents • metal carbenes • dirhodium(II) complexes

## 2.4 C–C Bond Formation Using Radicals

*W.-W. Chan and W.-Y. Yu*

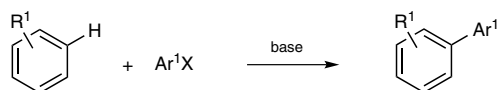
Direct C–H carbo-functionalization of (hetero)aromatic rings, as an atom-efficient route for regioselective C–C bond formation, is receiving current attention. In this review, radical coupling of unfunctionalized (het)arenes for C–C bond formation is described. Recent progress on the palladium-catalyzed regioselective C–H acylation of arenes with acyl radicals, as well as the transition-metal-free C–H arylation using aryl radicals, are presented. Some remarkable advances in the Minisci-type radical C–H alkylation of heterocycles are also discussed.

palladium-catalyzed radical acylation



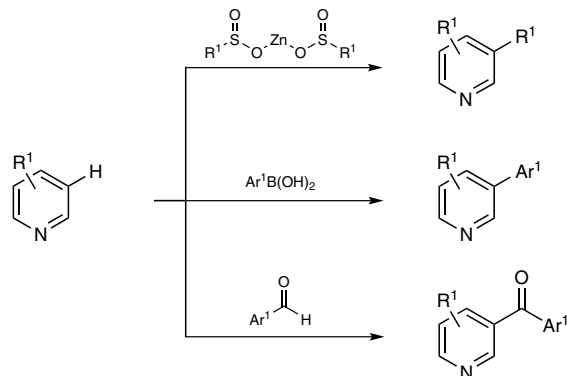
DG = oxime, amide, amine, azo; R<sup>1</sup> = aryl, alkyl, hetaryl

metal-free radical arylation



X = Br, I

Minisci-type radical coupling



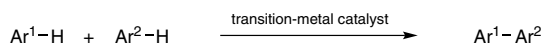
**Keywords:** C–H functionalization · organocatalysis · palladium · cross coupling · radicals · heterocycles

p 115

## 2.5 C–C Bond Formation by Double C–H Activation

*J.-B. Xia and S.-L. You*

This chapter focuses on transition-metal-catalyzed aryl–aryl bond-forming reactions via double C–H activation. Biaryl scaffolds have received much attention as a privileged structure broadly found in biologically active natural products, pharmaceuticals, agrochemicals, and functional molecules in material sciences, etc. Transition-metal-catalyzed cross-coupling reactions are the most general and efficient methods to synthesize biaryls, but both coupling partners need to be preactivated in transition-metal-catalyzed cross-coupling reactions when compared with simple arenes. Over the past decade, significant advances have been made in transition-metal-catalyzed biaryl synthesis using simple arenes as substrates via C–H activation. This chapter summarizes representative examples of transition-metal-catalyzed biaryl synthesis using two simple arenes as substrates via double C–H activation.



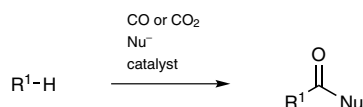
**Keywords:** transition-metal catalysis · double C–H activation · biaryl synthesis · directing groups

p 137

## 2.6 C–C Bond Formation by C–H Carboxylation or Carbonylation

*H. Zhang, C. Liu, and A. Lei*

The direct C–H carbonylation or carboxylation involving carbon monoxide is an ideal and environmentally friendly method toward the synthesis of carboxylic acids and derivatives. Within this emerging area, a number of significant examples have been reported, which are summarized in this chapter. Additionally, the recent progress on C–H carboxylation utilizing carbon dioxide is included in this review.



Nu = OH, OR<sup>2</sup>, NR<sup>2</sup>R<sup>3</sup>, R<sup>3</sup>

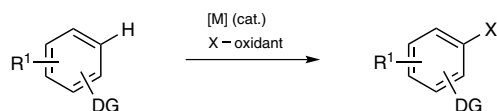
**Keywords:** C–H carbonylation · C–H carboxylation · carbon monoxide · carbon dioxide · directing groups · transition-metal catalysis · carboxylic acids · carboxylic esters · carboxylic amides · carbonyl compounds

p 183

## 2.7 C–Hal Bond Formation by Arene C–H Activation

*M. S. Sanford and A. Cook*

C<sub>aryl</sub>–H bonds are transformed into C<sub>aryl</sub>–halogen bonds via transition-metal-catalyzed C–H activation. Fluorination, chlorination, bromination, and iodination are discussed and a wide variety of arenes bearing various directing groups are competent substrates.



DG = directing group; X = F, Cl, Br, I

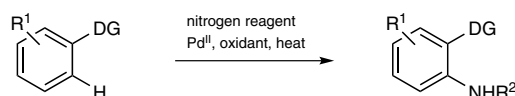
**Keywords:** halogens · carbon–halogen bonds · carbon–hydrogen bonds · regioselectivity · arenes · transition metals · pyridines · amides · quinoxalines · oximes · benzothiazoles · esters · benzonitriles · ketones · carboxylic acids

p 221

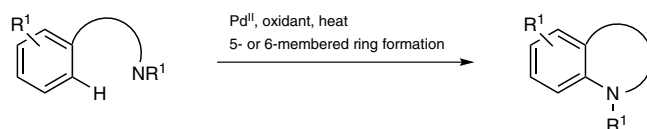
## 2.8 C–N Bond Formation by Arene C–H Activation Using a Palladium Catalyst

*P. Dauban and B. Darses*

The search for methodologies allowing C(sp<sup>2</sup>)–N bond formation is of utmost interest as the arylamine motif is ubiquitous in nature and life and material sciences. This chapter focuses on palladium-catalyzed arene C–H activation for the direct amination of C(sp<sup>2</sup>)–H bonds, generally under oxidizing conditions. These processes mainly allow the efficient introduction of carboxamides and sulfonamides, but the insertion of an amino group is also possible. Intramolecular transformations lead to the formation of either five-membered rings, such as carbazoles, indole derivatives, and benzo-fused nitrogen heterocycles, or six-membered rings, such as quinolinones and phenanthridinones. On the other hand, intermolecular reactions occur with complete regioselectivity, generally *ortho* to an appropriate directing group, which can be an oxime, a ketone, a carboxylic acid, or an amide.



DG = *ortho*-directing group



**Keywords:** palladium · arylamines · amination · intramolecular · intermolecular · regioselectivity · chemoselectivity · directing groups · carboxamides · sulfonamides · oxidants · heterocycles · carbazoles · indoles · dihydroindoles · oxindoles · benzimidazoles · benzotriazoles · quinolinones · phenanthridinones

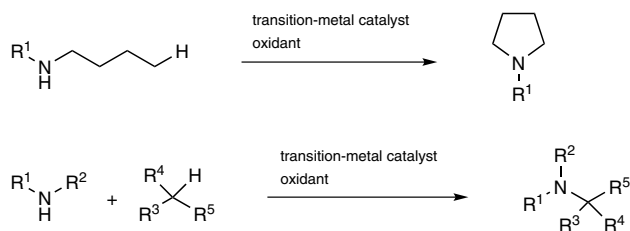
p 249

## 2.9 C–N Bond Formation by C–H Functionalization via Metal-Catalyzed Nitrene Insertion

*N. Mace Weldy and S. B. Blakey*

New routes for the formation of C–N bonds are important due to the prevalence of these bonds in complex natural products and molecules of pharmaceutical interest. Metallonitrene amination requires pre-oxidation of an amine, using precursors such as azides, *N*-(tosyloxy)carbamates, and iminoiodinanes. Binding of a transition-metal catalyst to the nitrene source gives the metallonitrene, which is capable of inserting into C–H bonds. Insertion may be made enantioselective in some systems by the use of a chiral metal complex. Most early examples of metallonitrene C–H amination focused on insertion into

benzylic C–H bonds, but recently the substrate scope has been expanded to include aryl, vinyl, and even unactivated tertiary, secondary, and primary bonds.



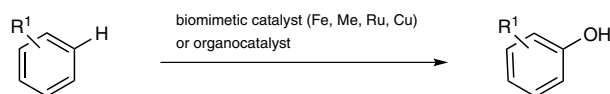
**Keywords:** amination · nitrenes · C–N bonds · enantioselectivity · rhodium catalysts · ruthenium catalysts · iridium catalysts · cobalt catalysts · iron catalysts

p 287

## 2.10 C–O Bond Formation by Arene C–H Activation via Biomimetic and Organocatalytic Oxidation

*Y. Hitomi and K. Arakawa*

This chapter is a summary of selected reactions for C–O bond formation via arene C–H bond activation by biomimetic and organocatalytic oxidation catalysts, which include manganese, iron, copper, and vanadium complexes as well as photocatalysts.



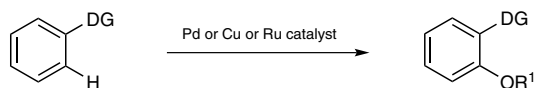
**Keywords:** arene complexes · arenes · hydroxylation · oxidation · oxygenation · quinones · phenols · porphyrins · iron catalysts · iron complexes · manganese catalysts · manganese complexes · ruthenium catalysts · ruthenium complexes · hydroperoxides · hydroquinones · copper catalysts · copper complexes

p 315

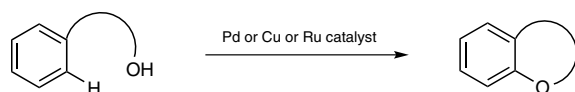
## 2.11 C–O Bond Formation by Arene C–H Activation via Metal-Catalyzed Oxidation

*D.-D. Li and G.-W. Wang*

This chapter highlights significant achievements in metal-catalyzed selective oxidation processes of arene C–H bonds to construct C–O bonds. A directing group is usually required to achieve high *ortho*-regioselectivity. Various functional groups have been fruitfully exploited as the directing groups for the acyloxylation, alkoxylation, hydroxylation, and intramolecular C–O cyclization of arenes by the palladium-, copper-, and ruthenium-catalyzed C–H activation. These transition-metal-catalyzed C–H/C–O processes can be efficiently achieved by utilizing either a monodentate or bidentate directing group.



DG = directing group; R<sup>1</sup> = Ac, CO<sub>2</sub>t-Bu, H, alkyl, etc.



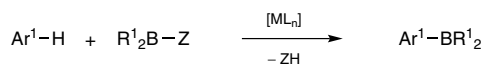
**Keywords:** arene C–H bond activation • C–O bond formation • palladium catalysis • copper catalysis • ruthenium catalysis • acyloxylation • alkoxylation • hydroxylation • intramolecular C–O cyclization

p 405

## 2.12 C–B Bond Formation by Arene C–H Activation

*A. Ros, R. Fernández, and J. M. Lassaletta*

This chapter provides a survey of the most useful available methodologies for the direct borylation of arenes and hetarenes, which proceed in all cases via a C–H activation event mediated by transition metals such as rhodium, iridium, or palladium. The borylation reactions have been organized into two main groups: (1) direct borylations with regioselectivity mainly controlled by steric factors, and (2) site-selective borylation, with regioselectivity driven by directing effects.



Ar<sup>1</sup> = aryl, hetaryl; Z = H, BR<sup>2</sup><sub>2</sub>

**Keywords:** C–H activation • organoboron compounds • borylation • arenes • hetarenes • synthetic methods • rhodium • iridium • palladium • directing groups